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Sediment Quality Issues within a Flood Control Reservoir, Little Tallahatchie County, MS

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EXECUTIVE SUMMARY

Since 1944, the USDA-NRCS has constructed over 10,000 upstream flood control dams in 2000 watersheds in 47 states, each with a design life of 50 years. The watershed projects have provided flood control, municipal water supply, recreation, and wildlife habitat enhancement. Because of population growth and land use changes through time, sediment pools are filling, some structural components have deteriorated, safety regulations are stricter, and the hazard classification for some dams has changed. Before any rehabilitation strategy can be designed and implemented, the sediment impounded by these dams must be assessed in terms of the structure's efficiency to regulate floodwaters and the potential hazard the sediment may pose if reintroduced into the environment. To this end, a project was designed to collect continuous, undisturbed sediment cores from the sediment pool of Hubbard-Murphree Dam Y-17-73 and to evaluate the physical and chemical characteristics of the sediment.

Since reservoirs such as Hubbard-Murphree represent a nearly 40-year record of continuous sedimentation, this record provides a number of opportunities to assess Total Maximum Daily Load (TMDL) criteria for sediment and the chemicals and nutrients including (1) determining natural or reference concentrations of elements, chemicals, compounds, and nutrients associated with the sediments, (2) assessing historical changes in land-use, hydrology, and agriculture, and (3) determining future adverse effects on the environment based on the rehabilitation design.

Hubbard-Murphree Dam Y-17-73 is located near Charleston, MS and it is a relatively small lake with a mud bottom and fairly shallow water depths. Dam construction was completed in the early 1960's. The reservoir has an upstream drainage area of 2,030 acres (822 ha).

A commercially available vibracoring system was used to obtain 6 undisturbed cores of unconsolidated sediment in nearly saturated conditions at Hubbard-Murphree. These cores ranged in length from 0.9 to 1.8 m and were extracted from water depths ranging from 0.6 to 1.5 m. In general, the sediment cores extracted at the Hubbard-Murphree reservoir are composed of alternating layers of silty clay, silty clay loam, and silt loam. Rates of sedimentation range from 20 to 42 mm/yr (typically 35 mm/yr) or 0.02 to 0.05 mm/ha-yr (typically 0.04 mm/ha-yr).

The concentrations of 33 elements within the sediments examined here do not vary significantly within each core or from core to core, although some elements decrease in concentration as depth increases. With respect to establishing TMDL for nutrients and elements associated with sediments, a table provided herein summarizes average concentrations for 33 elements spanning a time period of nearly 40 years. Two depth-integrated sediment samples were analyzed for 53 agrichemicals and contaminants, and no compounds were found above their detectable limits.

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INTRODUCTION

Federal Program for Flood Control

In response to devastating floods of the 1930's and 1940's, Congress enacted legislation for the construction of flood control dams on small tributary streams. The Flood Control Act of 1944 (PL-534) authorized 11 projects in the United States. Since 1948, more than 3,400 flood control dams have been constructed in the 320 subwatershed projects covering more than 35 million acres in 12 states (Caldwell, 1999).

In 1953, Congress enacted the Watershed Protection and Flood Prevention Act (PL-566), commonly referred to as the Small Watershed Program (Caldwell, 1999). Since that time, more than 6,300 flood control dams have been constructed in every state as well as Puerto Rico and the Pacific Rim, covering over 109 million acres.

The Pilot Watershed Program provided the transition between PL-534 and PL-566 (Caldwell, 1999). More than 400 flood control dams were constructed in 62 projects in 33 states, covering almost 3 million acres. In addition, the RC&D Program has provided technical and financial assistance to local sponsors for the planning, designing, and construction of more than 200 flood control dams since the 1960's.

In total, the U.S. Department of Agriculture, Natural Resources Conservation Service (USDA-NRCS) and its cooperators have constructed nearly 11,000 flood control dams in 47 states. More than $8.5 billion (1997 dollars) of federal funds and over $6.0 billion of local funds have been invested in these projects since 1948. This $14.5 billion infrastructure provides over $800 million in benefits annually.

The primary purposes for these structures were to prevent flooding and to protect watersheds. Other dams were built or have evolved into structures for water management, municipal and industrial water supply, recreation, and the improvement of fish and wildlife, water quality, and water conservation. Local sponsors were to provide leadership in the program and secure land rights and easements for construction. The USDA-NRCS was to provide technical assistance and cost-sharing for the construction of these dams.

Flood control dams typically consist of an earthen embankment 6 to 20-m high with a principal spillway made of concrete pipe 0.3 to 1.8-m wide (Caldwell, 1999). Because the dams were built on small streams in the upper reaches of watersheds, upstream drainage areas range from 1.6 to 16 km^2. The majority of these dams were planned and designed for a 50-year service life. The inlet pipe of the principal spillway is placed at an elevation that would provide water retention for the design storm and storage for sediment accumulation. Each reservoir also has an emergency or auxiliary spillway for safe conveyance of water around the embankment when runoff rates exceed storage capacity.

Current Status of Small Watershed Program

At present, more than half of the dams constructed are older than 34 years and more than 1,800 will reach their 50-year design life within the next 10 years (Caldwell, 2000). A rapid survey conducted in April 1999 revealed more than 2,200 dams in need of immediate rehabilitation at an estimated cost of more than $540 million. The primary issues of dam rehabilitation are: replacement of deteriorating components, change in hazard classification, reservoir sedimentation, failure to meet dam safety regulations, failure to meet resource needs of the watershed, inadequate land and water rights, inadequate community benefits, and the potential transfer of responsibility. Common approaches to address rehabilitation typically involve dredging the reservoir to remove accumulated sediment, raising the dam to increase storage capacity, and removing or decommissioning the dam.

Problem Statement

Before any rehabilitation strategy can be designed and implemented, the sediment impounded by these dams must be assessed in terms of the structure's efficiency to regulate floodwaters and the potential hazard the sediment may pose if reintroduced into the environment.

In discussions with Frank Adams, Geologist, USDA-NRCS, MS, select flood control dams within Mississippi were identified for pilot rehabilitation projects. Of these, one site, Hubbard-Murphree Dam Y-17-73 located in Tallahatchie County, MS, was chosen for investigation.

For a given lake within an embankment flood control structure, the USDA-NRCS needs to determine (1) the volume of sediment deposited, (2) the rates of sedimentation, (3) the quality of sediment with respect to agrichemicals (related to agricultural practices) and other contaminants, and (4) the spatial distribution of the sediment quality. Similar activities have recently been completed in Oklahoma (Bennett and Cooper, 2000, 2001; Bennett et al., 2001). To this end, a project was designed to collect continuous, undisturbed sediment cores from the sediment pool of Hubbard-Murphree Dam Y-17-73 and to evaluate the physical and chemical characteristics of the sediment.

Reservoir Sedimentation and TMDLs

Reservoirs such as Hubbard-Murphree represent a nearly 40-year record of continuous sedimentation. This record of deposition provides a number of opportunities to assess Total Maximum Daily Load (TMDL) criteria for sediment and the chemicals and nutrients associated with the sediment. First, the quality of the sediment impounded within the reservoir pool can be used to determine natural or reference concentrations of elements, chemicals, compounds, and nutrients delivered to the waterbody via the sediment over several decades. Hence, it would be quite easy to establish reference levels within the watershed. Second, the quality of the sediment can be used to assess historical changes in land-use, hydrology, and agriculture as these pertain to watershed processes. These changes could define a chronological link between land-use and sediment quality. Third, if the USDA-NRCS is required to remove the sediment as part of a dam rehabilitation strategy, the uncovered or dredged sediment may have significant adverse effects on the aquatic environment and water quality both within and downstream of the reservoir.

Global Positioning Satellite Systems

In order to construct maps depicting all activities, a global positioning satellite system (GPS) was employed. A commercially-available, hand-held global positioning receiver was used to demarcate the outline of the reservoir, the location of the embankment, the dam marker, the principal spillway drain, and any other pertinent geographic indicators. Data were collected by (1) setting the receiver to record positions at one-second intervals, (2) walking the desired geographic feature, and (3) logging the data to a file. Once completed, the operator would cease recording data. Files for each geographic feature were temporarily stored in the receiver and later downloaded to a personal computer. All positioning data were differentially corrected (DGPS) using base station data from Oxford, MS and commercially-available software. This base station is part of a network operated by the Department of Environmental Quality, Mississippi, and the corrections can be accessed through the following web-site: geology.deq.state.ms.us/gps/. Under optimum conditions, sub-meter accuracy of DGPS is possible. All data are presented in Universal Transverse Mercator (UTM) coordinates.

Field Site: Hubbard-Murphree Dam Y-17-73

Hubbard-Murphree Dam Y-17-73 is located near Charleston, MS and it is a relatively small lake with a mud bottom and fairly shallow water depths (up to 2 m; Figures 1 to 5). Dam construction was completed in the early 1960's. The structure was designed with storage capacities of 104 acre-feet for sediment and 735 acre-feet for floodwater. The reservoir has an upstream drainage area of 2,030 acres (822 ha). Approximately 4% of the watershed is currently cultivated, 42% is steep woodland, 36% is woodland, 18% is pasture, and less than 1% of the area is covered with roads. A base map of the dam and its environs constructed from DGPS information is shown in Figure 6.

Figure 1. Photograph of Hubbard-Murphree reservoir looking directly north showing principal spillway and earthen embankment in distance (September 2000).

Figure 2. Photograph of Hubbard-Murphree reservoir looking directly west. Principal spillway and earthen embankment are in distance on right (September 2000).

Figure 3. Photograph of Hubbard-Murphree reservoir looking southwest from the eastern side of lake (September 2000).

Figure 4. Photograph of principal spillway and earthen embankment at Hubbard-Murphree reservoir (September 2000). Note that the principal spillway is in disrepair and that the current water level is well below the designed stage.

Figure 5. Photograph of principal spillway and earthen embankment at Hubbard-Murphree reservoir (September 2000).

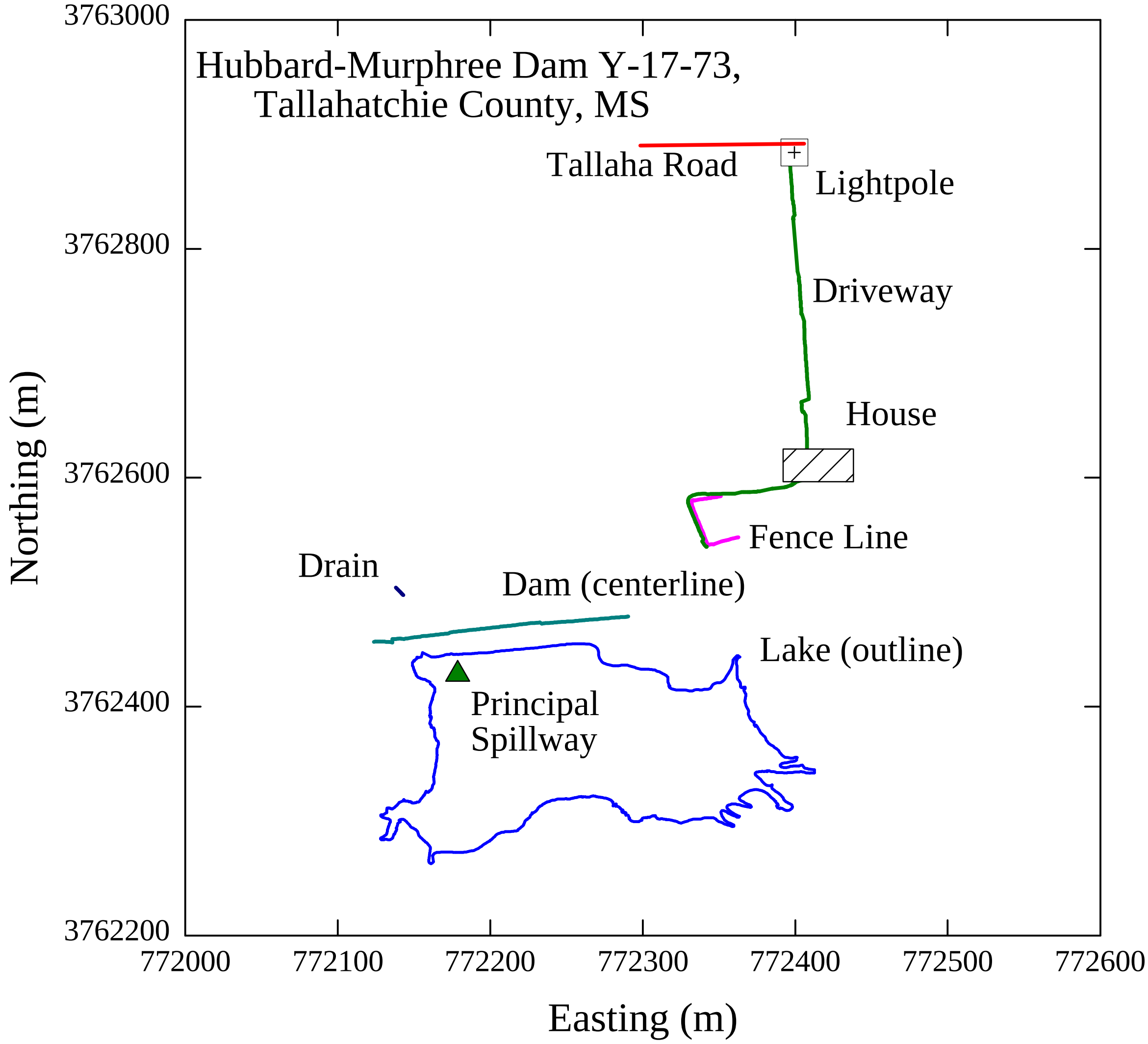

Figure 6. Generalized base map of Hubbard-Murphree Dam, Y-17-73, Tallahatchie County, MS showing locations of Tallaha Road, driveway, residence, fence line, dam centerline, spillway channel and drain, and outline of lake. All positions are in UTM coordinates.

VIBRACORING OF RESERVOIR SEDIMENTS

Vibracore System

Vibracoring is a common approach for obtaining undisturbed cores of unconsolidated sediment in saturated or nearly saturated conditions (Lanesky et al., 1979; Smith, 1984). Vibracoring works on the principle of transferring a high-frequency vibration to a thin-walled core pipe held in a vertical position on the sediment bed. The vibrating pipe causes the liquefaction or fluidization of sediment only at the core-sediment interface, thereby allowing the pipe to penetrate the sediment with little resistance and without disrupting sediment stratification.

A commercially available vibracoring system was used in this study (Figures 7, 8, and 9). This system uses a 1-HP motor that drives a pair of weights (masses) eccentrically mounted on two shafts and housed within a water-tight aluminum chamber (Figure 9). When in operation, the masses rotate in opposite directions causing the chamber to vibrate at frequencies ranging from 6000 to 8000 RPM depending upon the sediment substrate. The chamber (driver) is connected to the top of an aluminum irrigation pipe 1.5-mm thick, 76-mm wide, and over 3-m long and cabled to a 4.2-m high aluminum tripod fitted with a battery-operated winch (Figures 7, 8, and 9). Since the driver is sealed, the entire system can be immersed in water. A simple check valve placed into the flange connecting the core pipe to the driver induces internal suction during core extraction. The tripod is mounted to a raft that can be easily carried and assembled on site, towed with a small boat, and anchored into position (Figure 7).

Once the core was driven into the sediment, the vibrating motion was stopped and the winch lifted the core to the water surface (Figure 9). When successful, the core typically had a hard sediment bottom that acted as a seal. If excessive sand or gravel was present at the bottom of the core, the entire contents of the pipe would be lost during lifting. The position of the raft was recorded with a hand-held GPS receiver whose data were differentially corrected using available base station information. The core was transferred to the boat and transported to shore. Each core was transported back to the National Sedimentation Laboratory and opened by cutting the aluminum pipe length-wise on both sides with a circular saw, and the top half of the pipe was carefully lifted from the sediment (Figure 10). Typical photographs of the sediment within a core are shown in Figure 11.

Figure 7. Photograph of floating vibracore system showing the tripod and portable rafts. A core pipe is being connected to the vibracore head (September 2000).

Figure 8. Photograph of floating vibracore system showing the tripod and portable rafts. The pipe is being positioned to obtain a core (photograph taken in Oklahoma, June 2000).

Figure 9. Photograph of vibracore system showing the tripod, vibracore head, and winch and cable assembly (September 2000).

Figure 10. Photograph of extracted core being cut open on-site (photograph taken in Oklahoma, June 2000).

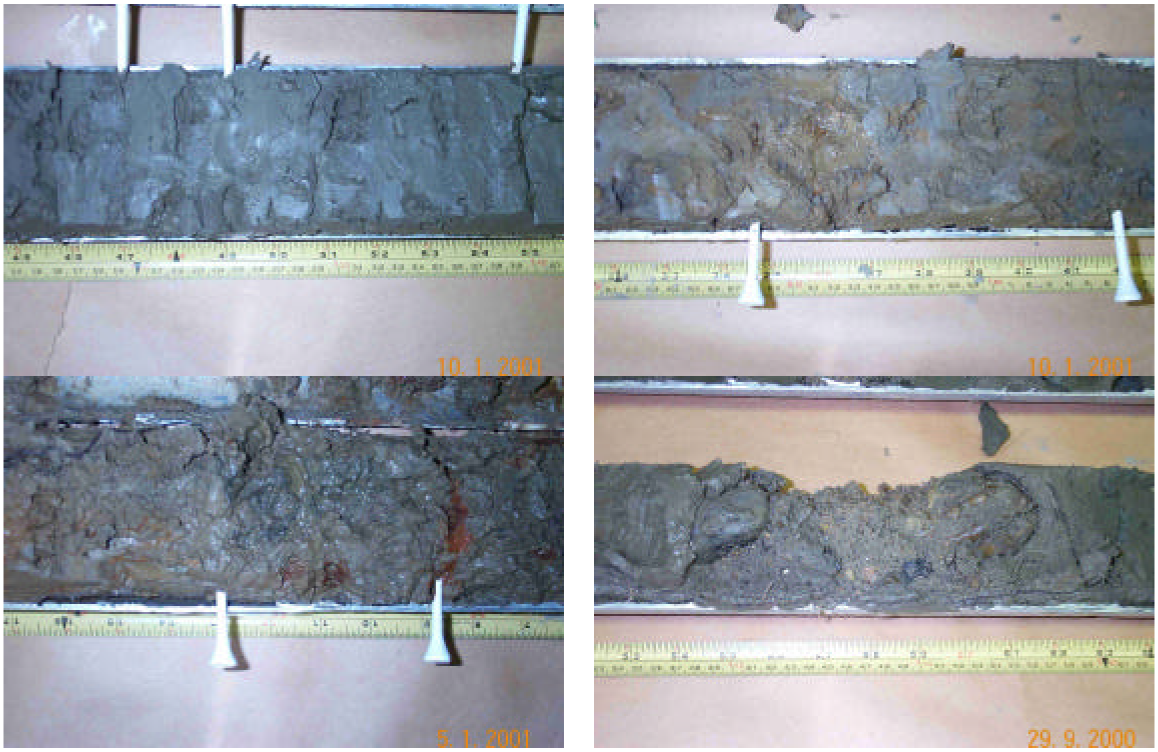

Figure 11. Typical photographs of sediment within Core 1 (upper left), Core 4 (upper and lower right), and Core 5 (lower left). White pegs were used to demarcate stratigraphic horizons (pointing downward) and millimeter-thick sand lenses (facing upward). Note gravel layer in lower right photograph.

Post-processing of Cores

After the core was opened, sediment samples were secured for laboratory analysis. First, each core was photographed and potential stratigraphic horizons were identified (see Figure 11). For the physical characterization of the sediment, approximately 200 g of sediment was secured at 30-mm increments along the entire length of the core. For agrichemical analysis, a depth-integrated sample of approximately 1 to 2 kg of sediment was secured and placed into a sterilized plastic bag.

Sediment Cores Obtained at Hubbard-Murphree Dam

Six continuous, undisturbed cores were obtained at Hubbard-Murphree and their positions are shown in Figure 12. These cores ranged in length from 0.9 to 1.8 m and were extracted from water depths ranging from 0.6 to 1.5 m.

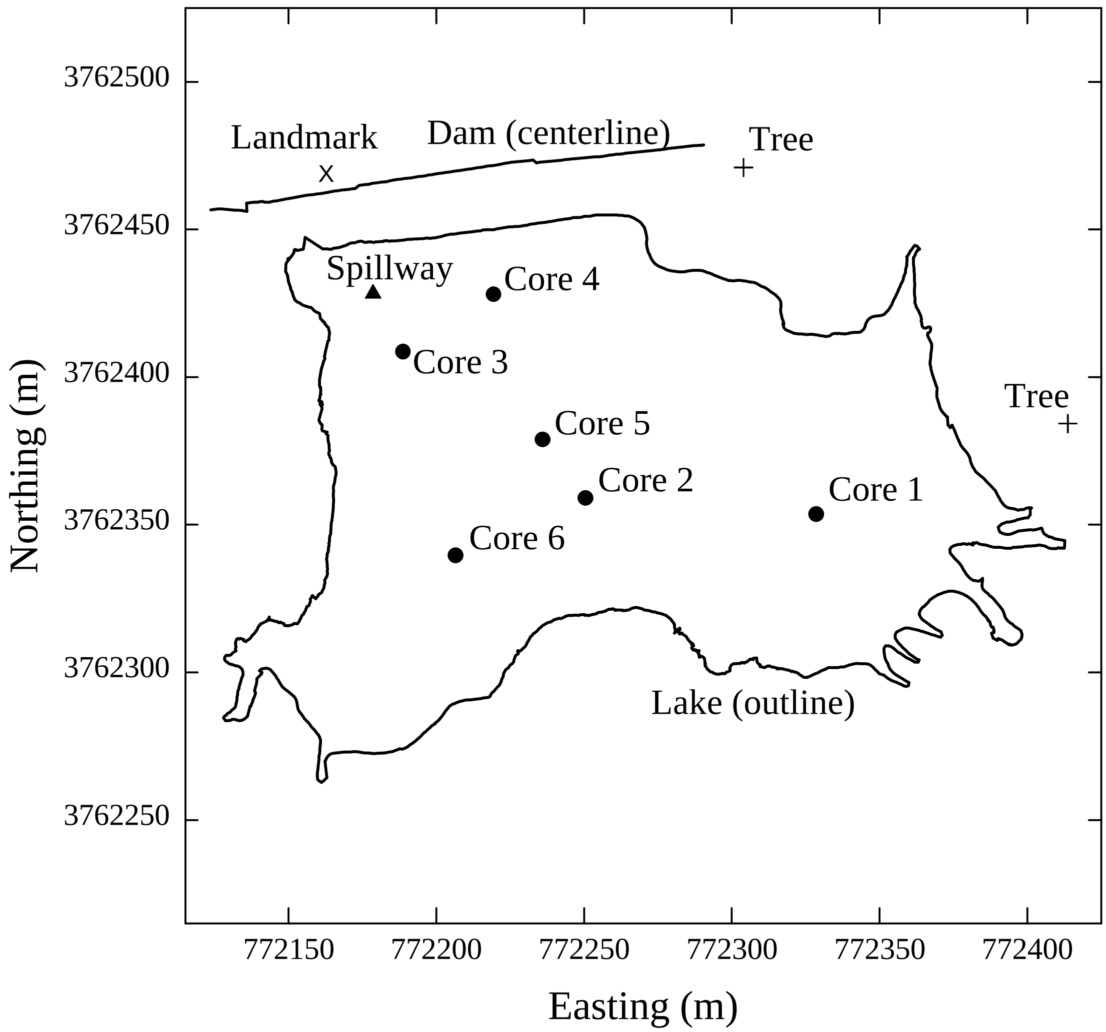

Figure 12. Detailed base map of Hubbard-Murphree Dam, Y-17-73, Tallahatchie County, MS showing locations of all cores (numbered 1-6), dam centerline, principal spillway, outline of lake, and select landmarks. All positions are in UTM coordinates.

Stratigraphic columns for each core are shown in Figures 13 to 18. The stratigraphic logs show the schematic textural characteristics of each core and the location of the sediment samples secured (e.g., GS 1, GS 2, etc.).

In general, the sediment cores extracted at the Hubbard-Murphree reservoir are composed of clay, silt, sand, and gravel of varying proportions. Most cores have alternating layers of silty clay, silty clay loam, and silt loam (see Core 2, Figure 14; Core 3, Figure 15; and Core 5, Figure 17). In places, relatively thick layers, as much as 1 m, of silt loam (see Core 1, Figure 13; Core 3, Figure 15; Core 4, Figure 16; and Core 6, Figure 18) and silty clay (Core 2, Figure 14) are common. Very thin layers rich in organic material or sand are also common. Most noteworthy is the ubiquitous gravel-laden sediment horizon near the base of each core. This horizon can be as thin as 50 mm (Core 1, Figure 13; Core 2, Figure 14; Core 3, Figure 15; and Core 5, Figure 17) or as thick as much as 0.1 to 0.2 m (Core 4, Figure 16; and Core 6, Figure 18). The gravel loamy sand at the base of Core 4 is shown in the lower right photograph of Figure 11.

Discussion

Using a vibracoring system, six continuous, undisturbed cores were obtained at Hubbard-Murphree and their positions spatially located. These cores ranged in length from 0.9 to 1.8 m and were extracted from water depths ranging from 0.6 to 1.5 m. In general, the sediment cores extracted at the Hubbard-Murphree reservoir are composed of clay, silt, sand, and gravel of varying proportions. Most cores have alternating layers of silty clay, silty clay loam, and silt loam. Most noteworthy is the ubiquitous gravel-laden sediment horizon near the base of each core.

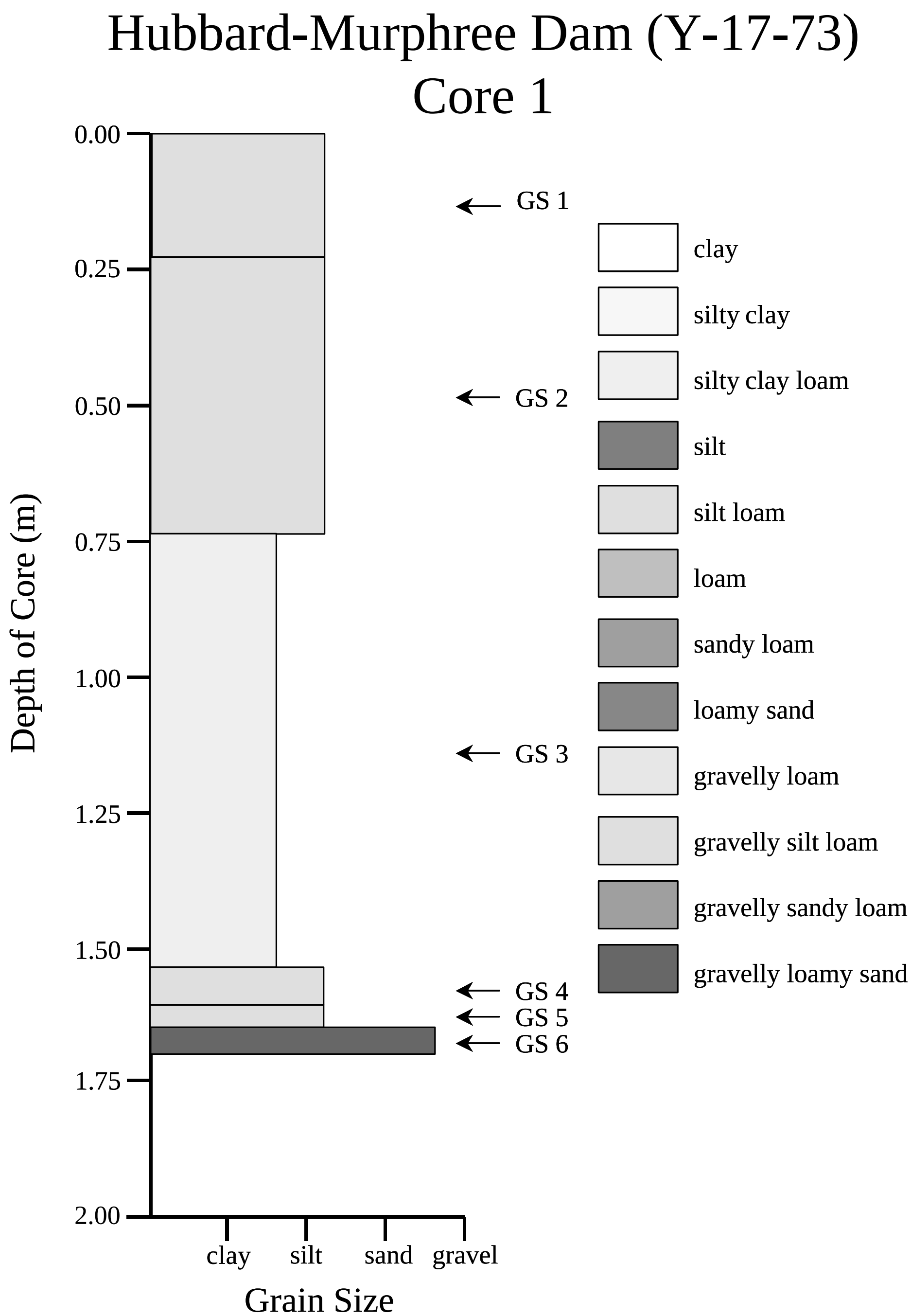

Figure 13. Stratigraphic log of Core 1 obtained at Hubbard-Murphree (see Figure 12 for exact location). Also shown are schematic textural characteristics of the units and the location of samples obtained for physical and chemical analysis (e.g. GS 1).

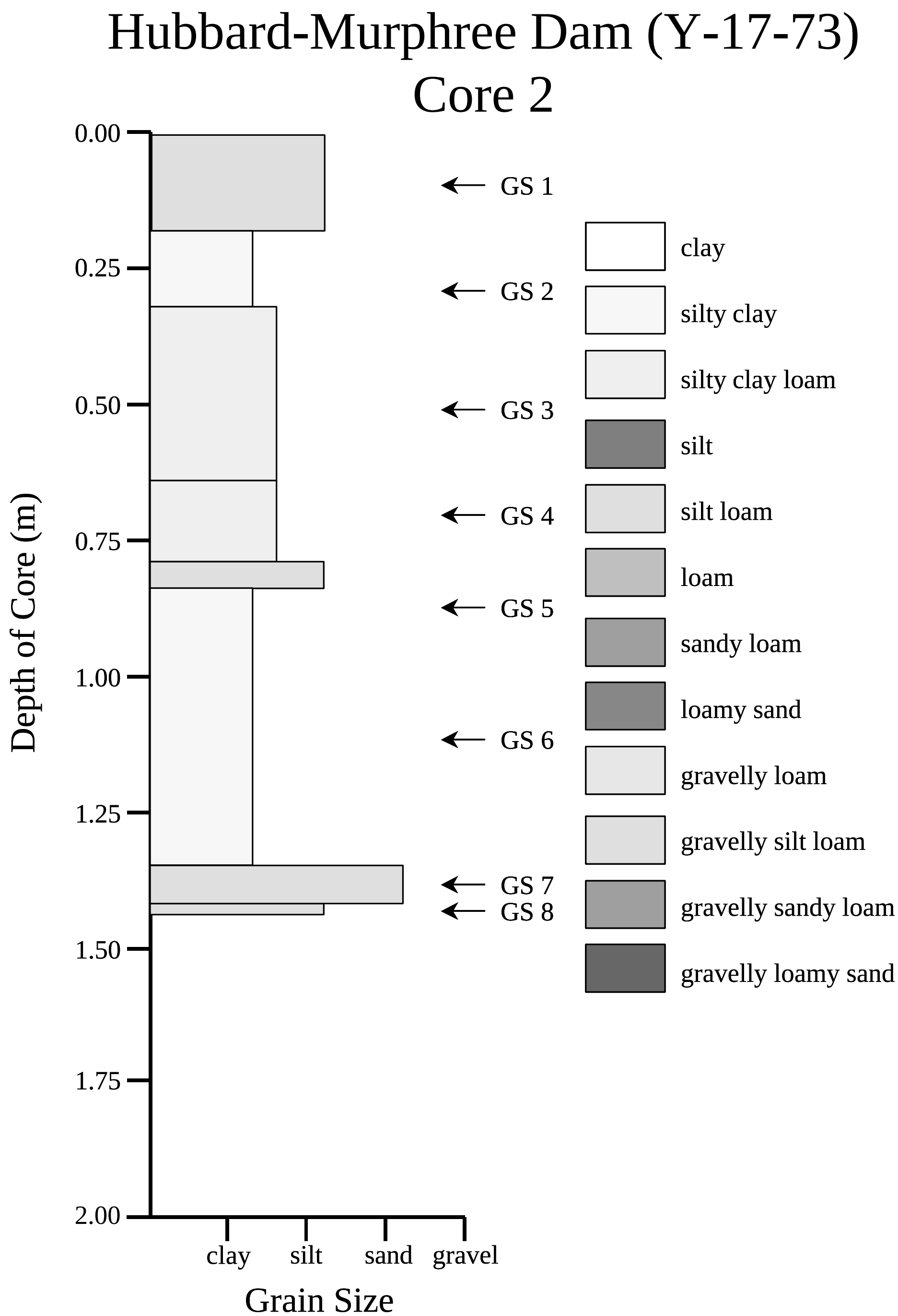

Figure 14. Stratigraphic log of Core 2 obtained at Hubbard-Murphree (see Figure 12 for exact location). Also shown are schematic textural characteristics of the units and the location of samples obtained for physical and chemical analysis (e.g. GS 1).

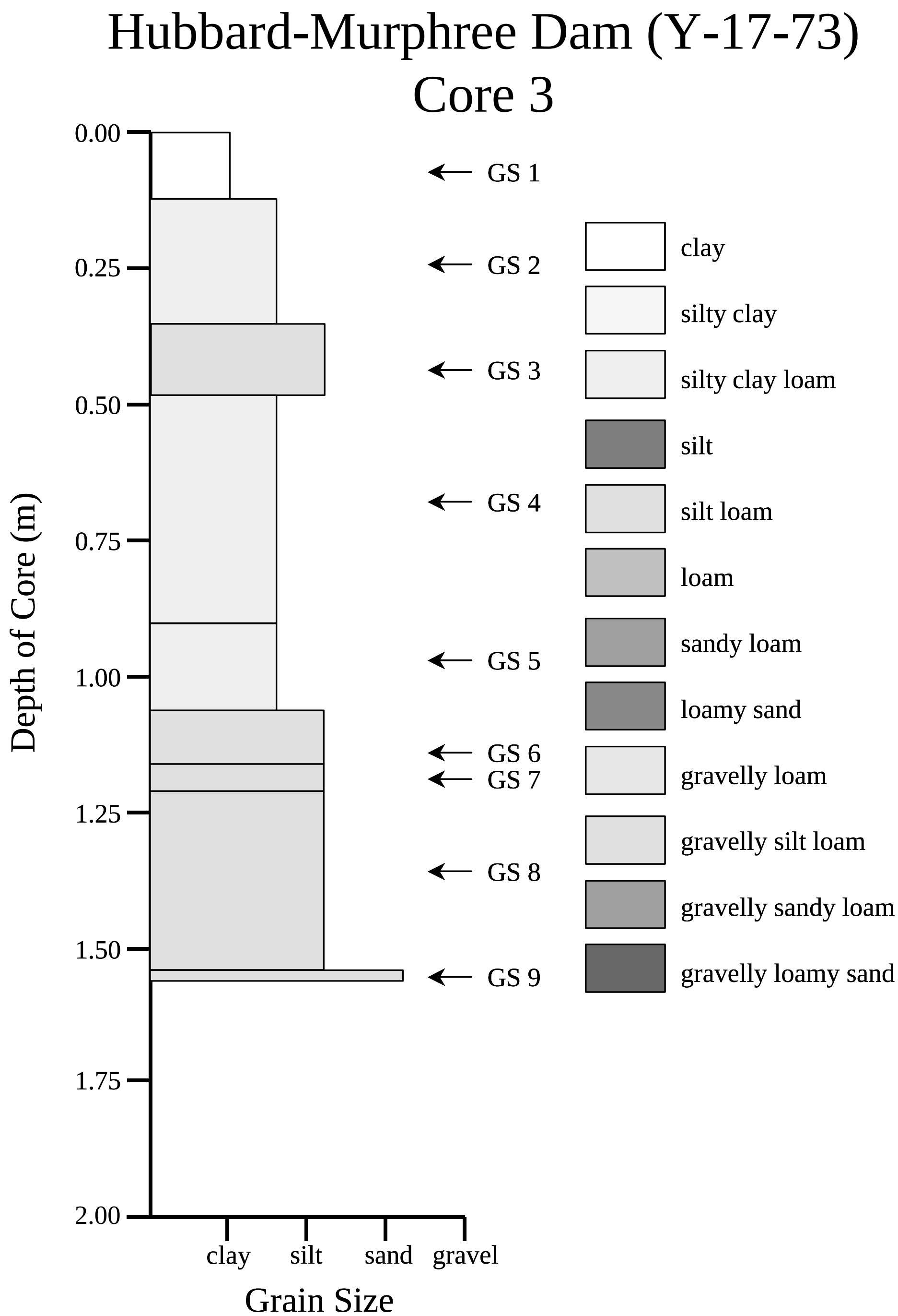

Figure 15. Stratigraphic log of Core 3 obtained at Hubbard-Murphree (see Figure 12 for exact location). Also shown are schematic textural characteristics of the units and the location of samples obtained for physical and chemical analysis (e.g. GS 1).

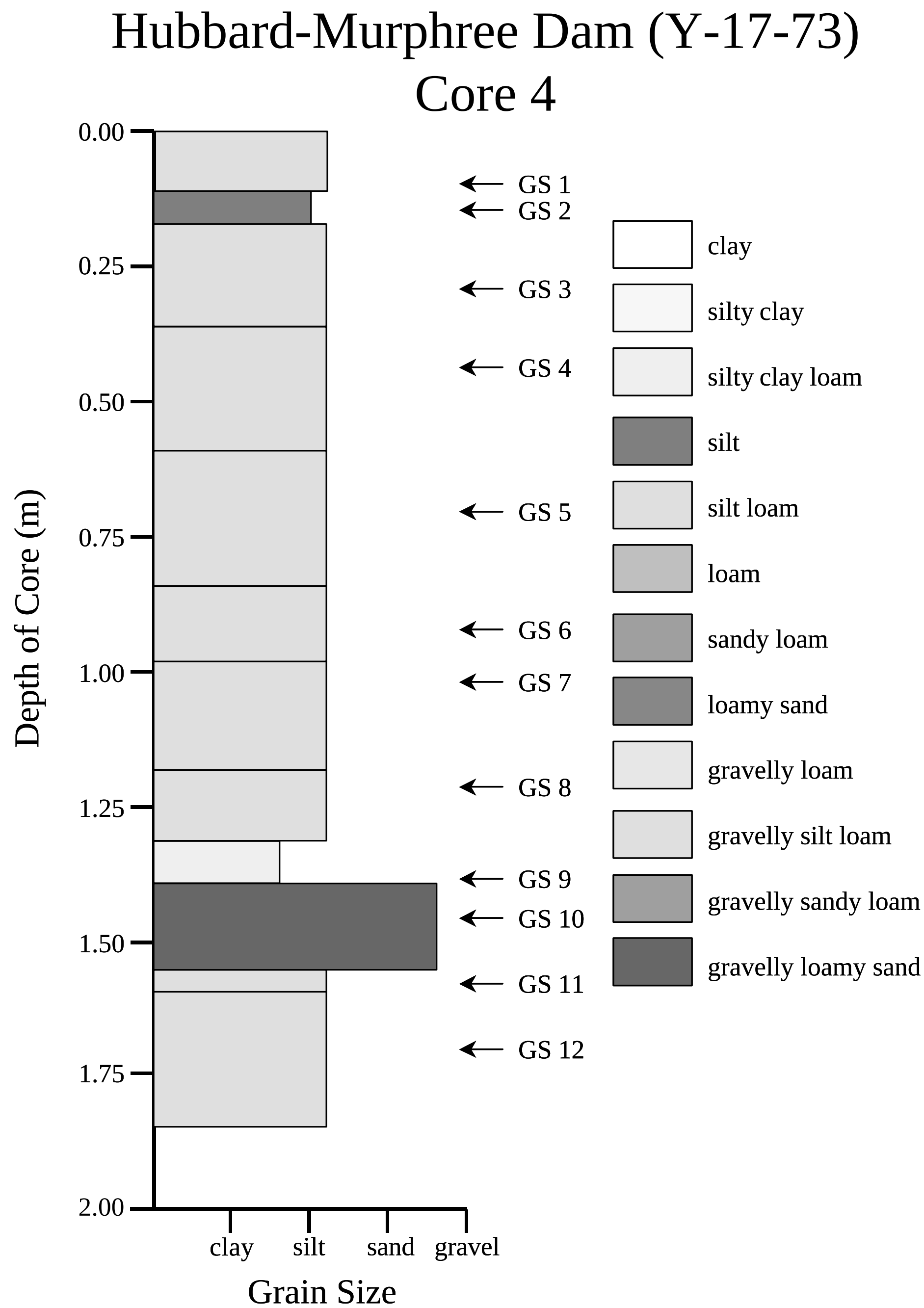

Figure 16. Stratigraphic log of Core 4 obtained at Hubbard-Murphree (see Figure 12 for exact location). Also shown are schematic textural characteristics of the units and the location of samples obtained for physical and chemical analysis (e.g. GS 1).

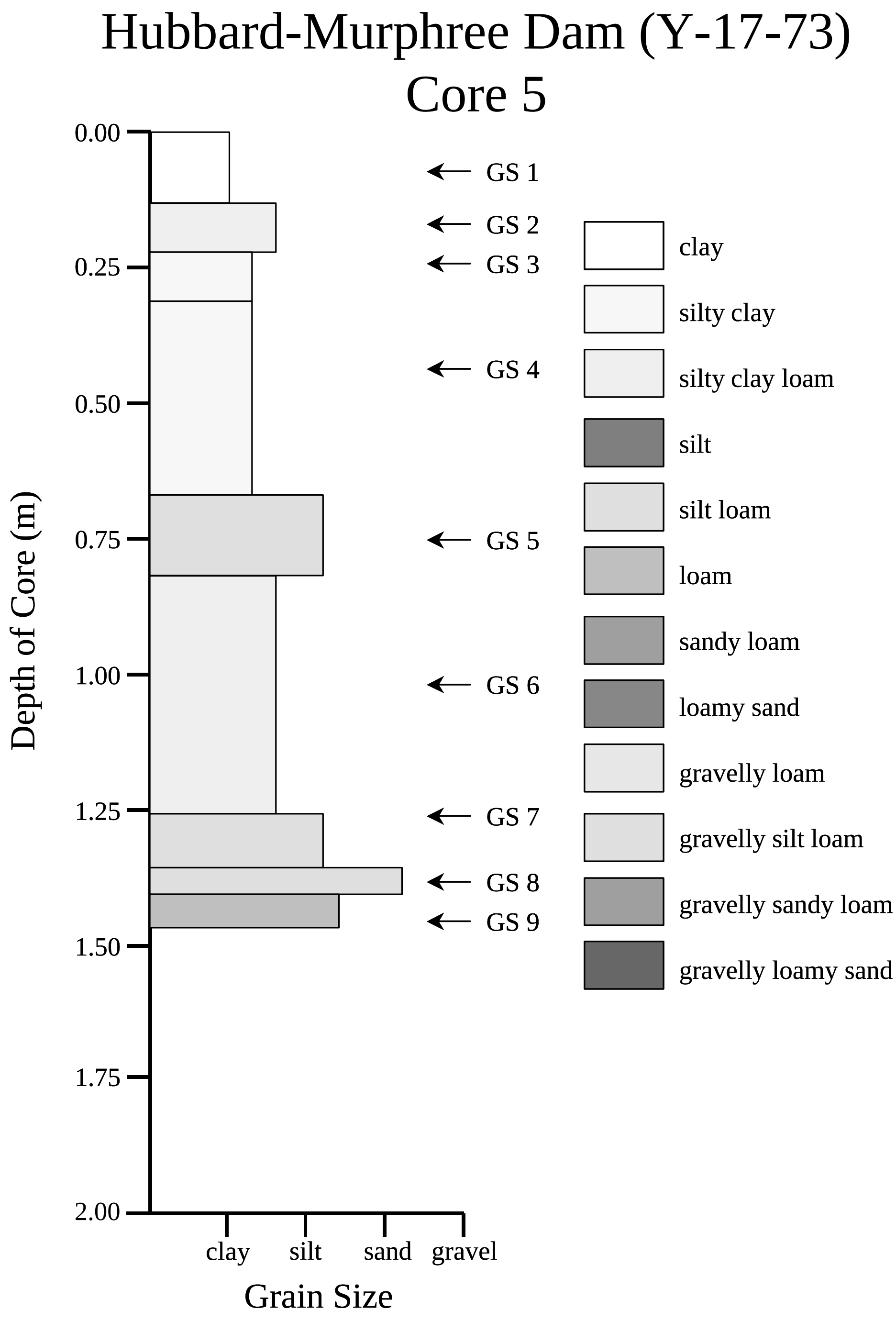

Figure 17. Stratigraphic log of Core 5 obtained at Hubbard-Murphree (see Figure 12 for exact location). Also shown are schematic textural characteristics of the units and the location of samples obtained for physical and chemical analysis (e.g. GS 1).

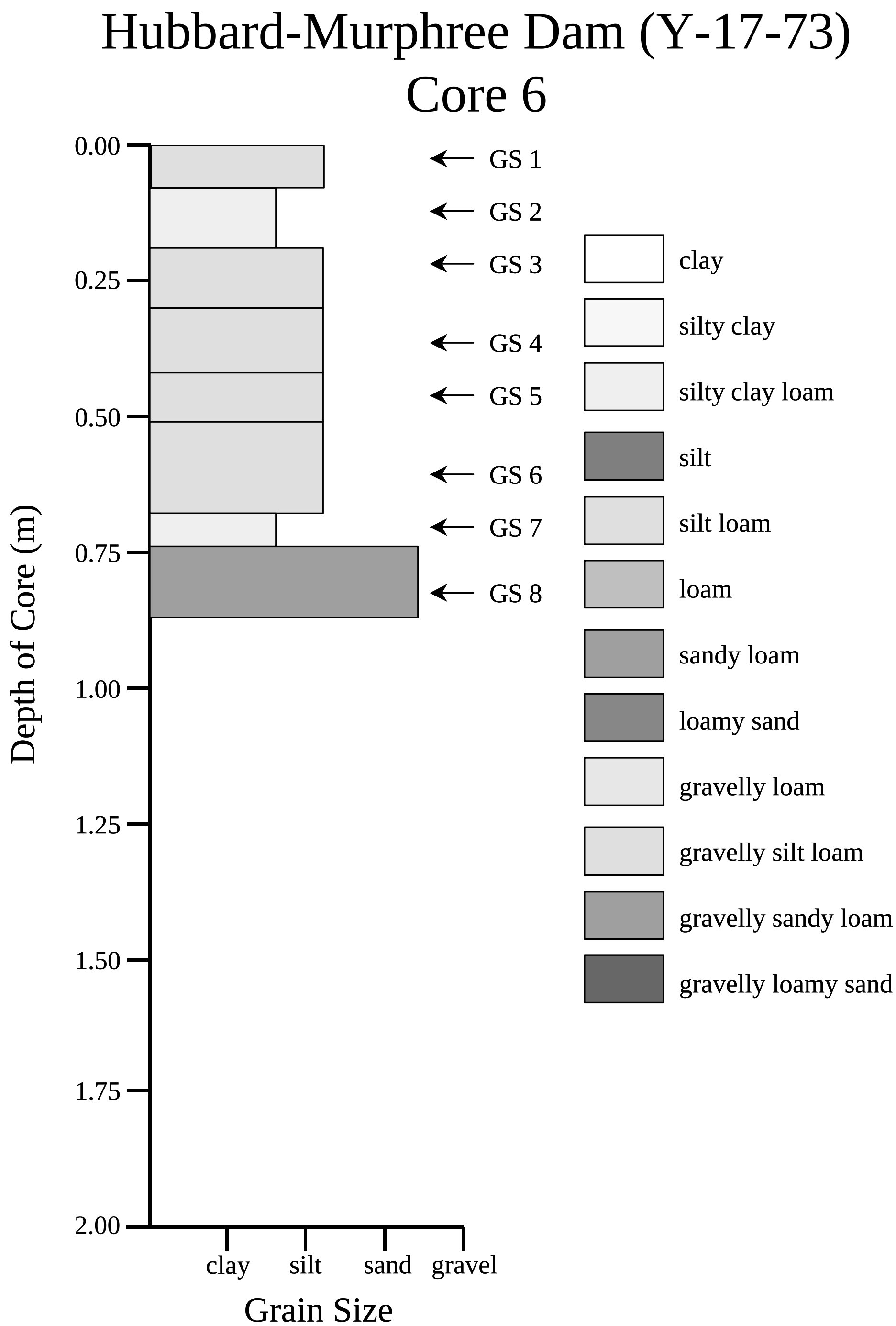

Figure 18. Stratigraphic log of Core 6 obtained at Hubbard-Murphree (see Figure 12 for exact location). Also shown are schematic textural characteristics of the units and the location of samples obtained for physical and chemical analysis (e.g. GS 1).

PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE RESERVOIR SEDIMENT

Select physical and chemical characteristics were determined for each of the sediment samples obtained from the major stratigraphic horizons identified in the cores. These physical and chemical characterizations include grain size analysis, magnetic susceptibility, percentage nitrogen and carbon, color, and bulk element analysis. The list of elements analyzed herein and their detection limits are listed in Table 1. All concentration results are tabulated in Table 2 for Core 1, Table 3 for Core 2, Table 4 for Core 3, Table 5 for Core 4, Table 6 for Core 5, and Table 7 for Core 6.

Methods and Procedures

For grain size analysis, approximately 10 g of sediment was treated in H_20_2 and shaken overnight in sodium hexametaphosphate for complete dispersion. Total percent clay (<0.002 mm) by mass was determined by siphoning off 5-mL of the dispersed sediment and using the pipette method (Method 3A1, Soil Survey Staff, 1992). Total percent sand by mass was determined by wet sieving the remaining sample through a 0.053-mm sieve and weighing the dried sediment retained. Total percent silt by mass was calculated by subtracting the masses of sand and clay from the original sample mass.

For magnetic susceptibility, dried and crushed sediment samples were packed into 20-mL glass vials and the mass specific magnetic susceptibility of the sample was measured using a Bartington MS2B susceptibility meter at a frequency of 0.47 kHz (values presented here are in SI units; 10^{-8} m^3/kg; see Lindbo et al., 1997). The magnetic susceptibility of each glass vial was determined prior to use.

Quantitative sediment color was determined using a chroma meter that employs a self-contained pulsed xenon arc lamp as a light source (Minolta CR-200 Chroma Meter; see Lindo et al., 1998). Water saturated sediment colors using the Munsell system of hue, value, and chroma are reported here (Munsell Color Company, 1994).

For some sediment samples, the concentration of select elements was determined. Approximately 3 to 4 g of sediment was secured from specific sediment horizons. These samples were dried, crushed, and mixed, and sent to XRAL Laboratories, Toronto, Canada. Each sampled was analyzed using (1) an inductively coupled plasma-mass spectrometer where the sediment sample was completely digested using multiple acid treatments, and (2) a flameless atomic adsorption analyzer.

Table 1. Listing of all chemical elements analyzed, their name, their units, and their detection limits for the sediment samples taken at Hubbard-Muphree Dam.

Element Symbol	Name	Units	Laboratory Detection Limit
Al	Aluminum	%	0.01
Sb	Antimony	ppm	5
As	Arsenic	ppm	3
Ba	Barium	ppm	1
Be	Beryllium	%	0.5
Bi	Bismuth	ppm	5
Cd	Cadmium	ppm	1
Ca	Calcium	%	0.01
Cr	Chromium	ppm	1
Co	Cobalt	ppm	0.5
Cu	Copper	ppm	0.5
Fe	Iron	%	0.01
La	Lanthanum	ppm	0.5
Pb	Lead	ppm	2
Li	Lithium	ppm	1
Mg	Magnesium	%	0.01
Mn	Manganese	ppm	2
Hg	Mercury	ppm	0.005
Mo	Molybdenum	ppm	1
Ni	Nickel	ppm	1
P	Phosphorus	%	0.01
K	Potassium	%	0.01
Sc	Scandium	ppm	0.5
Ag	Silver	ppm	0.2
Na	Sodium	%	0.01
Sr	Strontium	ppm	0.5
Sn	Tin	ppm	10
Ti	Titanium	%	0.01
W	Tungsten	ppm	10
V	Vanadium	ppm	2
Y	Yttrium	ppm	0.5
Zn	Zinc	ppm	0.5
Zr	Zirconium	ppm	0.5

Grain Size and Color Results

The grain size results show that most of the sediment deposited within the reservoir is composed of silt. Typically the sediment contains 80% silt and 20% clay by weight. Only minor amounts of sand and gravel are found in the cores, and these grain sizes are restricted to the lowest sediment horizons. High clay contents, as high as 60% (Core 3, Table 4) and 66% by weight (Core 5, Table 6) tend to occur near the tops of some cores. The sediment typically has a hue of 9.6YR or 0.1Y, a value of 3.8, and a chroma of 3.

Magnetic Susceptibility Results

The magnetic susceptibility of sediment is one measure of how easily the sediment can be magnetized by an external field, expressed as the ratio of the induced magnetization to the applied (Kimbrough et al., 1997). Magnetite has a magnetic susceptibility roughly three orders of magnitude greater than any other naturally occurring mineral (Lindsley et al., 1966), and therefore it largely controls this physical property in sediments. Magnetic susceptibility readings, however, are also weakly dependent on grain size, grain shape, and the presence of other magnetic minerals. Magnetic susceptibility ranges from 30 to 63 10^{-8} m^3/kg, but most values typically fall in the 35 to 40 10^{-8} m^3/kg range and display little variation both within cores and from core to core. As expected, the lowest values of magnetic susceptibility, as low as 7 10^{-8} m^3/kg (see sample 6, Core 1, Table 7), occurs when the sand content is high and clay content is low.

Nitrogen and Carbon Content Results

Very little nitrogen is present in the sediments at Hubbard-Murphree, typically much less than 0.1% by weight, with an average value around 0.05% (Table 8). Carbon is observed to range from 0.1 to 1.6% in the same sediments, with an average value around 0.64% (Table 8). The highest carbon contents occur near the top of the cores (see Core 3, Table 4; Core 5, Table 6; Core 6, Table 7), and carbon content appears to decrease with subsurface core depth.

Results from Bulk Elemental Analysis

Tables 2 to 7 summarize the concentration of 33 elements (see Table 1) for select samples within each core. Table 8 summarizes the average concentrations for each element based on those samples analyzed. In general, the concentrations for each element do not vary significantly. Core 1, though, does show lower concentrations for many of the elements listed in Table 8.

Table 2. Summary of physical and chemical characteristics of sediment samples taken from Core 1.

Parameter	Units	Sample 1	2	3	4	5	6
Depth	m	0.125	0.485	1.145	1.565	1.625	1.715
Sand	%	0.27	2.79	0.95	3.45	0.25	75.13
Silt	%	79.90	80.35	73.77	84.24	74.57	20.35
Clay	%	19.83	16.85	25.28	12.31	25.17	4.52
MS	10^{-8} m^3 kg^{-1}	34.68	36.33	38.88	37.35	33.08	7.02
Hue		NA	NA	NA	NA	NA	NA
Value		NA	NA	NA	NA	NA	NA
Chroma		NA	NA	NA	NA	NA	NA
Carbon	%	0.51	0.70	0.71	0.36	0.47	0.08
Nitrogen	%	0.03	0.03	0.05	0.02	0.04	ND
Be	%	1.4	1.2	1.3	1.0	1.5	ND
Na	%	0.72	0.70	0.64	0.75	0.74	0.10
Mg	%	0.35	0.33	0.38	0.25	0.40	0.05
Al	%	6.06	5.33	5.98	4.47	6.58	0.93
P	%	0.06	0.05	0.06	0.03	0.06	0.01
K	%	1.65	1.60	1.57	1.51	1.72	0.24
Ca	%	0.31	0.33	0.30	0.32	0.30	0.05
Sc	ppm	6.7	6.0	6.8	4.7	7.2	1.1
Ti	%	0.45	0.43	0.44	0.40	0.44	0.11
V	ppm	76	71	77	52	81	15
Cr	ppm	35	30	43	22	31	5
Mn	ppm	542	499	693	378	424	71
Fe	%	2.70	2.31	2.70	1.69	2.80	0.55
Co	ppm	14	9	12	11	12	3
Ni	ppm	24	22	24	16	27	5
Cu	ppm	24.2	19.4	21.3	17.0	26.5	3.8
Zn	ppm	67.6	61.8	71.1	44.3	75.0	12.1

Table 2 continued

Parameter	Units	Sample					
		1	2	3	4	5	6
As	ppm	ND	ND	ND	ND	ND	ND
Sr	ppm	101.0	98.1	90.6	99.0	101.0	18.0
Y	ppm	15.5	14.5	15.6	13.2	16.5	3.9
Zr	ppm	122.0	122.0	121.0	122.0	110.0	29.9
Mo	ppm	ND	ND	ND	ND	ND	ND
Ag	ppm	0.5	0.3	0.2	ND	0.4	ND
Cd	ppm	ND	ND	ND	ND	ND	ND
Sn	ppm	ND	ND	ND	ND	ND	ND
Sb	ppm	ND	ND	ND	ND	ND	ND
Ba	ppm	576	550	543	507	592	104
La	ppm	32.4	31.2	31.1	30.1	33.1	9.9
W	ppm	33	26	28	57	30	36
Pb	ppm	17	13	13	11	16	8
Bi	ppm	ND	ND	ND	ND	ND	ND
Li	ppm	19	18	20	15	22	4
Hg	ppm	0.11	0.10	0.13	0.08	0.11	0.06

ND—not detected; NA—not available

Table 3. Summary of physical and chemical characteristics of sediment samples taken from Core 2.

Parameter	Units	Sample 1	2	3	4	5	6	7	8
Depth	m	0.095	0.275	0.515	0.725	0.845	1.115	1.415	1.445
Sand	%	2.76	0.30	0.16	0.08	0.47	0.21	0.17	7.61
Silt	%	82.58	59.22	74.05	64.79	78.67	54.91	76.76	69.36
Clay	%	14.66	40.47	25.79	35.13	20.86	44.88	23.07	23.02
MS	10^{-8} m^3 kg^{-1}	37.74	33.84	37.66	44.49	37.36	41.27	31.21	43.05
Hue		NA	NA	NA	NA	NA	NA	NA	NA
Value		NA	NA	NA	NA	NA	NA	NA	NA
Chroma		NA	NA	NA	NA	NA	NA	NA	NA
Carbon	%	0.67	0.95	0.49	0.80	0.55	0.98	0.39	0.40
Nitrogen	%	0.04	0.09	0.04	0.07	0.05	0.09	0.03	0.03
Be	%	1.1	1.8	1.5	1.7	1.3	1.9	1.4	1.4
Na	%	0.75	0.58	0.73	0.61	0.78	0.53	0.77	0.63
Mg	%	0.29	0.50	0.40	0.51	0.39	0.58	0.37	0.38
Al	%	4.89	7.14	6.40	7.40	5.63	8.00	5.86	5.91
P	%	0.05	0.09	0.06	0.08	0.05	0.10	0.06	0.06
K	%	1.61	1.72	1.70	1.74	1.76	1.76	1.71	1.55
Ca	%	0.32	0.28	0.30	0.30	0.33	0.31	0.30	0.28
Sc	ppm	5.5	8.1	7.0	8.5	6.5	9.5	6.4	6.8
Ti	%	0.42	0.51	0.42	0.47	0.45	0.49	0.42	0.40
V	ppm	62	106	80	100	75	115	76	78
Cr	ppm	26	69	36	42	48	72	34	75
Mn	ppm	387	805	544	647	410	1440	383	385
Fe	%	2.05	3.79	2.94	3.54	2.52	4.40	2.58	2.75
Co	ppm	12	13	13	13	10	15	10	10
Ni	ppm	20	34	25	32	23	40	24	46
Cu	ppm	23.3	29.0	20.7	40.6	22.6	41.4	23.5	23.4
Zn	ppm	56.2	98.7	73.7	95.4	67.6	115.0	70.0	73.2

Table 3 continued

Parameter	Units	Sample							
		1	2	3	4	5	6	7	8
As	ppm	ND	ND	ND	ND	ND	ND	ND	ND
Sr	ppm	100.0	84.5	98.0	89.9	102.0	89.2	101.0	89.8
Y	ppm	14.3	16.8	15.1	16.2	14.5	18.1	15.2	15.2
Zr	ppm	129	119	108	109	123	110	113	100
Mo	ppm	1	2	2	1	ND	3	2	3
Ag	ppm	0.3	0.3	ND	0.3	ND	0.2	ND	ND
Cd	ppm	ND	ND	ND	ND	ND	ND	ND	ND
Sn	ppm	ND	ND	ND	ND	ND	ND	ND	ND
Sb	ppm	ND	ND	ND	ND	ND	ND	ND	ND
Ba	ppm	533	603	575	589	580	610	579	528
La	ppm	29.8	31.1	31.3	32.8	31.0	34.8	31.7	30.6
W	ppm	82	16	26	16	26	13	13	27
Pb	ppm	14	18	16	19	13	24	10	14
Bi	ppm	ND	ND	ND	ND	ND	ND	ND	ND
Li	ppm	16	27	21	25	20	30	21	21
Hg	ppm	0.05	0.08	0.06	0.07	0.05	0.09	0.05	0.05

ND—not detected; NA—not available

Table 4. Summary of physical and chemical characteristics of sediment samples taken from Core 3.

Parameter	Units	Sample 1	2	3	4	5	6	7	8	9
Depth	m	0.065	0.245	0.425	0.695	0.965	1.115	1.175	1.355	1.535
Sand	%	0.58	0.10	0.22	0.08	3.67	28.43	20.81	32.23	29.72
Silt	%	40.33	65.13	76.48	66.73	67.83	59.16	64.41	57.35	60.91
Clay	%	59.09	34.77	23.29	33.19	28.50	12.41	14.77	10.41	9.36
MS	10^{-8} m^3 kg^{-1}	51.23	37.30	41.67	35.00	34.42	58.67	63.19	38.70	34.70
Hue		NA	NA	NA	NA	NA	NA	NA	NA	NA
Value		NA	NA	NA	NA	NA	NA	NA	NA	NA
Chroma		NA	NA	NA	NA	NA	NA	NA	NA	NA
Carbon	%	1.60	0.62	0.57	0.52	0.45	0.37	0.52	0.47	0.53
Nitrogen	%	0.14	0.05	0.04	0.04	0.04	0.01	0.03	0.01	0.01
Be	%	2.3	1.6	1.6	1.8	1.5	0.9	0.9	0.9	1.1
Na	%	0.42	0.62	0.78	0.67	0.69	0.56	0.61	0.62	0.58
Mg	%	0.76	0.48	0.44	0.53	0.43	0.24	0.28	0.23	0.19
Al	%	8.05	6.58	6.81	7.87	6.13	3.19	4.24	3.83	3.41
P	%	0.14	0.09	0.07	0.08	0.06	0.04	0.04	0.05	0.03
K	%	1.83	1.72	1.87	1.87	1.72	1.12	1.27	1.24	1.14
Ca	%	0.35	0.27	0.34	0.33	0.30	0.24	0.27	0.32	0.25
Sc	ppm	11.0	8.0	7.8	9.4	7.3	3.8	5.1	4.5	4.2
Ti	%	0.50	0.46	0.43	0.53	0.49	0.33	0.31	0.34	0.30
V	ppm	148	98	89	108	91	50	56	50	42
Cr	ppm	88	69	57	71	83	149	150	41	33
Mn	ppm	1140	731	681	773	546	761	299	575	337
Fe	%	6.03	3.48	3.23	3.83	2.96	1.92	2.05	1.75	1.35
Co	ppm	20	13	15	15	14	13	12	11	11
Ni	ppm	53	37	28	36	35	47	52	17	15
Cu	ppm	44.4	29.2	23.8	29.0	27.3	22.1	23.4	14.3	16.6
Zn	ppm	158.0	92.7	82.1	104.0	85.0	44.8	63.7	42.6	37.0

Table 4 continued

Parameter	Units	Sample								
		1	2	3	4	5	6	7	8	9
As	ppm	8	ND	ND	ND	ND	ND	ND	ND	ND
Sr	ppm	82.0	86.8	107.0	101.0	95.8	71.7	87.9	88.6	80.8
Y	ppm	23.2	16.7	16.5	18.8	17.5	10.8	12.2	13.2	11.5
Zr	ppm	112	114	121	128	131	111	104	115	102
Mo	ppm	2	ND	ND	2	2	3	4	ND	ND
Ag	ppm	0.5	ND	0.5	0.4	ND	ND	ND	0.3	0.3
Cd	ppm	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sn	ppm	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sb	ppm	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ba	ppm	647	596	635	626	581	393	446	439	410
La	ppm	38.4	32.7	34.0	36.6	32.8	23.2	26.6	26.5	24.1
W	ppm	14	16	26	21	26	65	69	85	103
Pb	ppm	30	18	16	17	14	12	14	10	11
Bi	ppm	ND	ND	ND	ND	ND	ND	ND	ND	ND
Li	ppm	34	26	22	27	24	12	13	12	11
Hg	ppm	0.13	0.11	0.11	0.11	0.09	0.07	0.05	0.09	0.05

ND—not detected; NA—not available

Table 5. Summary of physical and chemical characteristics of sediment samples taken from Core 4.

		Sample Number											
Parameter	Units	1	2	3	4	5	6	7	8	9	10	11	12
Depth	m	0.065	0.155	0.275	0.485	0.725	0.905	1.085	1.235	1.355	1.475	1.565	1.715
Sand	%	0.29	0.51	0.26	0.21	0.14	0.06	0.35	0.07	0.35	47.13	0.41	15.59
Silt	%	78.49	86.91	72.92	80.99	80.47	74.46	79.34	80.40	69.87	48.84	85.54	66.53
Clay	%	21.22	12.58	26.82	18.80	19.39	25.48	20.31	19.53	29.79	4.03	14.05	17.88
MS	10^{-8} $m^3\,kg^{-1}$	44.5	39.6	37.0	36.7	47.6	45.3	42.1	41.3	38.3	46.9	31.0	48.6
Hue		9.6 YR	9.4YR	0.1Y	9.3YR	9.9YR	0.1Y	9.6YR	9.7YR	9.8YR	0.1Y	0.1Y	0.1Y
Value		3.4	3.7	4.0	3.8	3.8	3.8	3.9	4.1	3.9	4.1	3.8	4.1
Chroma		2.9	2.7	2.8	3.3	3.7	3.0	2.9	3.0	3.0	2.6	3.0	3.1
Carbon	%	0.98	0.69	0.93	0.57	0.89	0.83	0.73	0.58	0.67	0.21	0.38	0.22
Be	%	1.6	1.1	1.4	1.2	1.4	1.4	1.3	1.4	1.5	ND	1.1	0.9
Na	%	0.59	0.70	0.60	0.63	0.56	0.62	0.59	0.6	0.59	0.26	0.78	0.67
Mg	%	0.63	0.35	0.49	0.43	0.53	0.53	0.49	0.51	0.55	0.10	0.37	0.37
Al	%	7.09	4.92	6.62	6.09	6.81	6.44	6.44	6.47	6.88	1.53	5.24	4.38
P	%	0.09	0.06	0.08	0.07	0.09	0.08	0.08	0.07	0.08	0.02	0.05	0.05
K	%	1.89	1.65	1.71	1.66	1.74	1.82	1.69	1.74	1.79	0.55	1.70	1.37
Ca	%	0.30	0.27	0.26	0.25	0.28	0.24	0.27	0.25	0.29	0.11	0.35	0.28
Sc	ppm	11.9	6.2	8.2	7.3	8.5	8.1	8.2	8.5	8.9	2.0	6.3	6.0
Ti	%	0.39	0.36	0.39	0.37	0.38	0.36	0.38	0.36	0.39	0.15	0.35	0.29
V	ppm	110	69	97	86	104	99	95	96	103	23	69	66
Cr	ppm	65	42	40	50	56	55	56	52	59	41	47	51
Mn	ppm	790	525	747	694	1540	609	1050	543	592	146	584	857
Fe	%	4.18	2.48	3.44	3.06	3.94	3.44	3.51	3.31	3.57	0.84	2.26	2.56
Co	ppm	35	19	20	15	22	14	13	14	14	7	10	13
Ni	ppm	38	22	33	27	38	33	36	33	37	47	24	40
Cu	ppm	33.7	18.1	25.5	22.4	35.1	27.1	28.3	27.5	26.3	9.0	15.7	21.6
Zn	ppm	122.0	66.6	94.3	77.6	101.0	99.4	91.2	94.8	105.0	18.2	66.0	64.6

Table 5 continued

Parameter	Units	Sample Number											
		1	2	3	4	5	6	7	8	9	10	11	12
As	ppm	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	5
Sr	ppm	90.8	93.9	87.8	87.9	87.4	89.3	90.0	91.8	94.3	39.6	108.0	98.4
Y	ppm	24.3	14.1	16.5	14.3	16.2	14.3	16.1	16.2	18.3	7.2	14.4	14.4
Zr	ppm	117.0	105.0	92.9	92.0	90.1	86.6	91.7	90.3	93.2	56.3	101.0	91.9
Mo	ppm	3	1	2	ND	2	2	2	2	ND	4	1	3
Ag	ppm	0.4	0.3	0.5	0.3	0.6	0.3	0.3	0.4	ND	ND	0.4	0.2
Cd	ppm	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sn	ppm	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sb	ppm	6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ba	ppm	624	533	590	557	593	596	581	595	606	200	575	502
La	ppm	33.4	28.3	31.8	28.8	31.5	30.4	32.0	32.6	34.8	14.0	29.3	28.1
W	ppm	234	368	144	79	101	39	37	34	24	180	70	82
Pb	ppm	17	12	16	14	18	18	17	16	16	6	9	13
Bi	ppm	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Li	ppm	34	22	30	27	31	29	29	29	33	7	22	17
Hg	ppm	0.109	0.102	0.095	0.093	0.106	0.115	0.112	0.107	0.103	0.015	0.075	0.071

ND—not detected; NA—not available

Table 6. Summary of physical and chemical characteristics of sediment samples taken from Core 5.

Parameter	Units	Sample 1	2	3	4	5	6	7	8	9
Depth	m	0.065	0.185	0.245	0.485	0.755	1.025	1.295	1.385	1.445
Sand	%	0.89	0.41	0.21	0.17	0.20	0.06	25.71	37.68	42.62
Silt	%	32.90	60.00	56.98	54.45	77.35	63.35	58.66	53.61	48.06
Clay	%	66.22	39.59	42.81	45.38	22.45	36.59	15.63	8.71	9.32
MS	10^{-8} m^3 kg^{-1}	48.1	43.3	36.2	46.6	39.3	35.9	46.7	54.3	44.5
Hue		NA	NA	NA	NA	NA	NA	NA	NA	NA
Value		NA	NA	NA	NA	NA	NA	NA	NA	NA
Chroma		NA	NA	NA	NA	NA	NA	NA	NA	NA
Carbon	%	1.40	1.00	0.95	1.07	0.60	0.69	0.34	0.27	0.26
Nitrogen	%	0.14	0.09	0.09	0.11	0.05	0.06	0.01	0.01	0.003
Be	%	2.4	1.8	1.8	2.1	1.4	1.9	1.0	0.7	0.7
Na	%	0.47	0.62	0.55	0.54	0.71	0.61	0.53	0.49	0.45
Mg	%	0.85	0.57	0.53	0.63	0.40	0.51	0.26	0.17	0.16
Al	%	9.27	7.70	7.98	8.08	5.81	7.13	4.15	2.89	2.77
P	%	0.19	0.11	0.09	0.12	0.06	0.07	0.04	0.03	0.03
K	%	1.93	1.80	1.69	1.84	1.67	1.76	1.16	0.94	0.90
Ca	%	0.38	0.33	0.30	0.33	0.31	0.30	0.24	0.22	0.20
Sc	ppm	13.3	9.8	9.4	10.1	6.8	8.3	4.9	3.4	3.3
Ti	%	0.50	0.47	0.47	0.54	0.44	0.48	0.32	0.24	0.25
V	ppm	155	108	108	127	79	105	54	39	35
Cr	ppm	96	54	64	78	58	65	58	139	47
Mn	ppm	1130	823	797	1080	520	645	283	266	333
Fe	%	6.37	4.26	3.92	4.84	2.77	3.66	1.88	1.41	1.34
Co	ppm	21	20	18	17	12	19	11	15	10
Ni	ppm	60	39	36	42	25	34	41	76	41
Cu	ppm	49.7	31.2	31.1	34.6	26.4	35.6	16.0	13.6	13.5
Zn	ppm	169.0	108.0	105.0	125.0	74.5	103.0	49.1	33.4	31.5

Table 6 continued

Parameter	Units	Sample								
		1	2	3	4	5	6	7	8	9
As	ppm	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sr	ppm	84.8	94.6	85.8	89.0	97.4	93.1	75.8	67.5	61.9
Y	ppm	24.0	19.9	18.5	18.2	15.0	16.7	12.3	10.2	10.6
Zr	ppm	112.0	116.0	109.0	125.0	122.0	111.0	95.4	85.4	84.9
Mo	ppm	1	1	ND	2	1	2	2	5	4
Ag	ppm	0.4	ND	ND	0.4	ND	0.3	0.4	ND	ND
Cd	ppm	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sn	ppm	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sb	ppm	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ba	ppm	662	602	578	619	569	614	407	349	331
La	ppm	39.2	36.2	35.3	33.2	30.5	33.0	25.2	20.5	23.3
W	ppm	14	33	17	12	39	68	79	139	134
Pb	ppm	30	21	16	24	11	21	9	7	8
Bi	ppm	ND	ND	ND	ND	ND	ND	ND	ND	ND
Li	ppm	35	27	27	28	20	27	14	10	9
Hg	ppm	0.09	0.08	0.09	0.09	0.07	0.09	0.04	0.03	0.03

ND—not detected; NA—not available

Table 7. Summary of physical and chemical characteristics of sediment samples taken from Core 6.

Parameter	Units	Sample 1	2	3	4	5	6	7	8
Depth	m	0.035	0.125	0.245	0.365	0.455	0.605	0.695	0.815
Sand	%	1.18	0.09	1.94	0.36	0.09	1.37	2.24	66.00
Silt	%	80.77	69.15	81.58	75.10	76.05	78.01	62.25	29.73
Clay	%	18.05	30.76	16.49	24.54	23.86	20.61	35.51	4.27
MS	10^{-8} m^3 kg^{-1}	46.2	38.7	40.6	44.3	40.5	40.4	43.0	57.3
Hue		0.1Y	0.4Y	0.5Y	0.1Y	0.1Y	0.1Y	9.5YR	0.5Y
Value		3.7	3.4	3.7	3.7	3.9	3.9	3.8	3.7
Chroma		2.4	2.4	2.4	3.1	2.7	3.1	3.0	2.7
Carbon	%	1.54	0.97	0.42	0.65	0.66	0.43	0.73	0.23
Be	%	1.5	1.5	1.0	1.3	1.5	1.3	1.5	ND
Na	%	0.60	0.56	0.76	0.62	0.65	0.71	0.60	0.18
Mg	%	0.57	0.53	0.31	0.47	0.46	0.44	0.50	0.07
Al	%	6.53	7.19	4.52	6.19	6.06	5.93	6.53	1.14
P	%	0.08	0.09	0.04	0.07	0.07	0.06	0.07	0.01
K	%	1.75	1.71	1.59	1.67	1.72	1.77	1.70	0.39
Ca	%	0.33	0.27	0.27	0.27	0.27	0.27	0.29	0.09
Sc	ppm	9.0	9.1	5.3	7.7	7.9	7.3	8.6	1.6
Ti	%	0.36	0.40	0.32	0.35	0.35	0.35	0.36	0.11
V	ppm	101	105	61	90	86	85	97	18
Cr	ppm	78	37	30	58	47	68	88	60
Mn	ppm	732	760	410	697	708	706	783	134
Fe	%	3.68	3.80	2.09	3.16	3.09	2.96	3.38	0.73
Co	ppm	15	13	8	12	12	12	13	11
Ni	ppm	43	34	26	31	30	36	48	70
Cu	ppm	29.5	26.5	18.1	24.0	23.0	21.1	25.1	13.3
Zn	ppm	110.0	103.0	55.0	85.8	85.2	82.3	99.6	19.2
As	ppm	ND	ND	ND	ND	ND	ND	ND	ND

Table 7 continued

Parameter	Units	Sample							
		1	2	3	4	5	6	7	8
Sr	ppm	94.6	89.9	96.9	90.8	93.4	98.9	93.8	28.8
Y	ppm	23.3	17.7	12.6	14.8	15.2	14.9	18.2	5.5
Zr	ppm	92.6	94.9	96.2	93.2	91.4	96.0	96.5	43.6
Mo	ppm	3	2	2	2	3	2	2	6
Ag	ppm	0.2	0.5	0.3	0.5	0.4	0.4	0.4	ND
Cd	ppm	ND	ND	ND	ND	ND	ND	ND	ND
Sn	ppm	ND	ND	ND	ND	ND	ND	ND	ND
Sb	ppm	ND	ND	ND	ND	ND	ND	ND	ND
Ba	ppm	588	603	517	567	577	595	569	158
La	ppm	33.6	34.2	26.0	29.9	30.4	30.4	34.1	11.1
W	ppm	35	26	74	30	30	44	30	393
Pb	ppm	18	18	10	15	15	11	17	6
Bi	ppm	ND	ND	ND	ND	ND	ND	ND	ND
Li	ppm	30	31	19	27	28	26	31	6
Hg	ppm	0.107	0.131	0.086	0.142	0.121	0.121	0.102	0.035

ND—not detected; NA—not available

Table 8. Average concentrations for all chemical elements in sediment samples taken for each core and for all core samples.

Parameter	Units	Core						All
		1	2	3	4	5	6	Samples
Carbon	%	0.47	0.65	0.63	0.64	0.73	0.70	0.64
Nitrogen	%	0.03	0.06	0.04	NA	0.06	NA	0.05
Be	%	1.07	1.51	1.40	1.19	1.53	1.20	1.32
Na	%	0.61	0.67	0.62	0.60	0.55	0.59	0.61
Mg	%	0.29	0.43	0.40	0.45	0.45	0.42	0.41
Al	%	4.89	6.40	5.57	5.74	6.20	5.51	5.72
P	%	0.05	0.07	0.07	0.07	0.08	0.06	0.07
K	%	1.38	1.69	1.53	1.61	1.52	1.54	1.55
Ca	%	0.27	0.30	0.30	0.26	0.29	0.26	0.28
Sc	ppm	5.42	7.29	6.79	7.51	7.70	7.06	6.96
Ti	%	0.38	0.45	0.41	0.35	0.41	0.33	0.39
V	ppm	62.00	86.50	81.33	84.75	90.00	80.38	80.83
Cr	ppm	27.67	50.25	82.33	51.17	73.22	58.25	57.15
Mn	ppm	434.50	625.13	649.22	723.08	653.00	616.25	616.86
Fe	%	2.13	3.07	2.96	3.05	3.38	2.86	2.91
Co	ppm	10.17	12.00	13.78	16.33	15.89	12.00	13.36
Ni	ppm	19.67	30.50	35.56	34.00	43.78	39.75	33.88
Cu	ppm	18.70	28.06	25.57	24.19	27.97	22.58	24.51
Zn	ppm	55.32	81.23	78.88	83.39	88.72	80.01	77.93
As	ppm	ND	ND	0.89	0.42	ND	ND	0.22
Sr	ppm	84.62	94.30	89.07	88.27	83.32	85.89	87.58
Y	ppm	13.20	15.68	15.60	15.53	16.16	15.28	15.24
Zr	ppm	104.48	113.88	115.33	92.33	106.74	88.05	103.47
Mo	ppm	0.00	1.75	1.44	2.20	2.00	2.75	1.69
Ag	ppm	0.28	0.14	0.22	0.37	0.17	0.34	0.25
Cd	ppm	ND	ND	ND	ND	ND	ND	ND
Sn	ppm	ND	ND	ND	ND	ND	ND	ND

Table 8 continued

Parameter	Units	Core						All
		1	2	3	4	5	6	Samples
Sb	ppm	ND	ND	ND	0.50	ND	ND	0.08
Ba	ppm	478.67	574.63	530.33	546.00	525.67	521.75	529.51
La	ppm	27.97	31.64	30.54	29.58	30.71	28.71	29.86
W	ppm	35.00	27.38	47.22	116.00	59.44	82.75	61.30
Pb	ppm	13.00	16.00	15.78	14.33	16.33	13.75	14.87
Bi	ppm	ND	ND	ND	ND	ND	ND	ND
Li	ppm	16.33	22.63	20.11	25.83	21.89	24.75	21.92
Hg	ppm	0.10	0.06	0.09	0.09	0.07	0.11	0.09

ND—not detected; NA—not available

Depth Variation of Physical and Chemical Characteristics

Figures 19 through 23 show the variation of each element for each sediment core as a function of depth below the lake bottom. Sediment texture, magnetic susceptibility, and percent of carbon and nitrogen are also plotted.

Numerous elements show no change in concentration with depth: Be, Na, K, and Ca, Figure 19; Ti, Cr, Co, Ni, and Cu, Figure 20; Sr, Y, Zr, Mo, and Ag, Figure 21; Ba, La, W, and Pb, Figure 22; and Hg, Figure 23. Some elements decrease in concentration as depth increases: Mg, Al, P, and Sc Figure 19; V, Mn, and Fe, Figure 20; Zn, Figure 21; and Li, Figure 22. Some elements show a great deal of variability both with depth and from core to core (Ni and Cu, Figure 20; Mo and Ag, Figure 21; and Li, Figure 22), while other elements show little variability (Sr and Y, Figure 21; and Hg, Figure 23). Some elements, except in a few samples, were not detected in the analysis: As and Cd, Figure 21; Sn, Sb, and Bi, Figure 22). In some instances, the concentration of select elements was significantly different to those stratigraphically above or below: Ni and Cu, Figure 20; Mo and Ag, Figure 21; and Li, Figure 22. In addition, both carbon and nitrogen decrease in concentration with increasing depth (Figure 23).

The Linkage Between Sediment Chemistry and Sediment Texture

While the previous section described spatial variations of sediment chemistry within and amongst the cores, there is a clear link between sediment chemistry and sediment texture. Figure 24 plots the concentration of select elements as a function of percent clay by weight. For all those chosen, element concentration is strongly correlated to the amount of clay within the sample. Although clay content in the sediment typically is about 20% by weight, the concentration of environmentally important elements such as nutrients and heavy metals can increase by several factors with moderate increases in clay content.

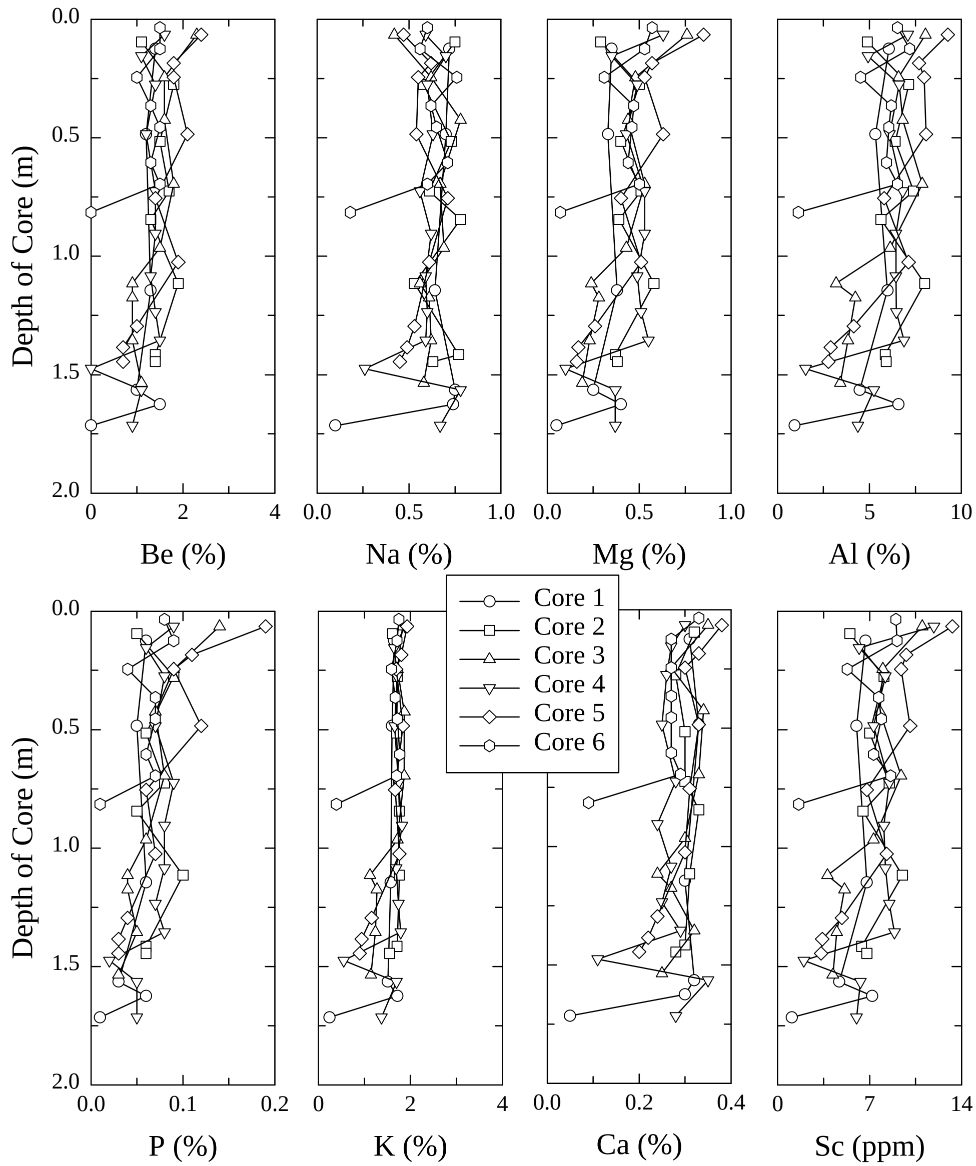

Figure 19. Summary of select chemical results (Be, Na, Mg, Al, P, K, Ca, and Sc) as a function of depth below the sediment surface (see Table 1 for detection limits, and Tables 2 through 7).

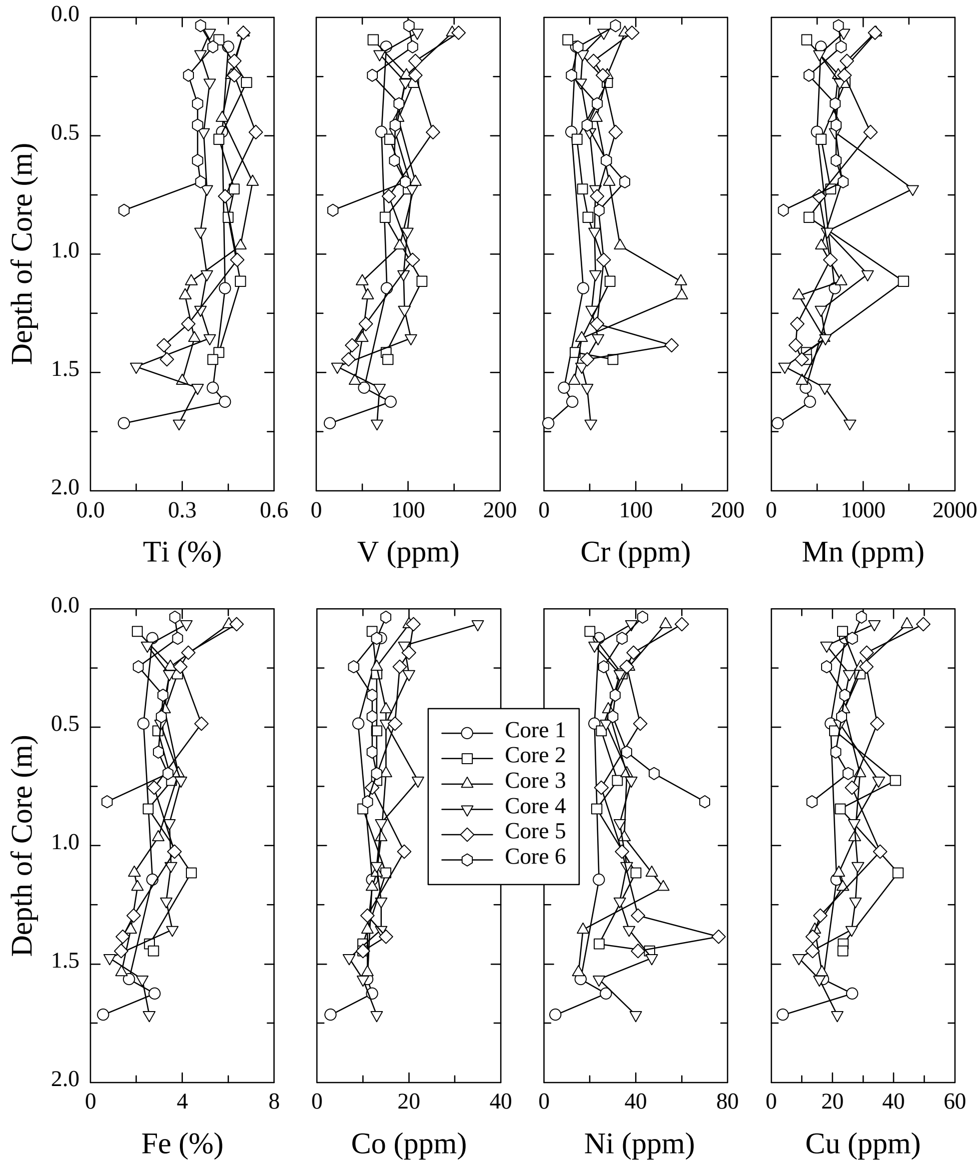

Figure 20. Summary of select chemical results (Ti, V, Cr, Mn, Fe, Co, Ni, and Cu) as a function of depth below the sediment surface (see Table 1 for detection limits, and Tables 2 through 7).

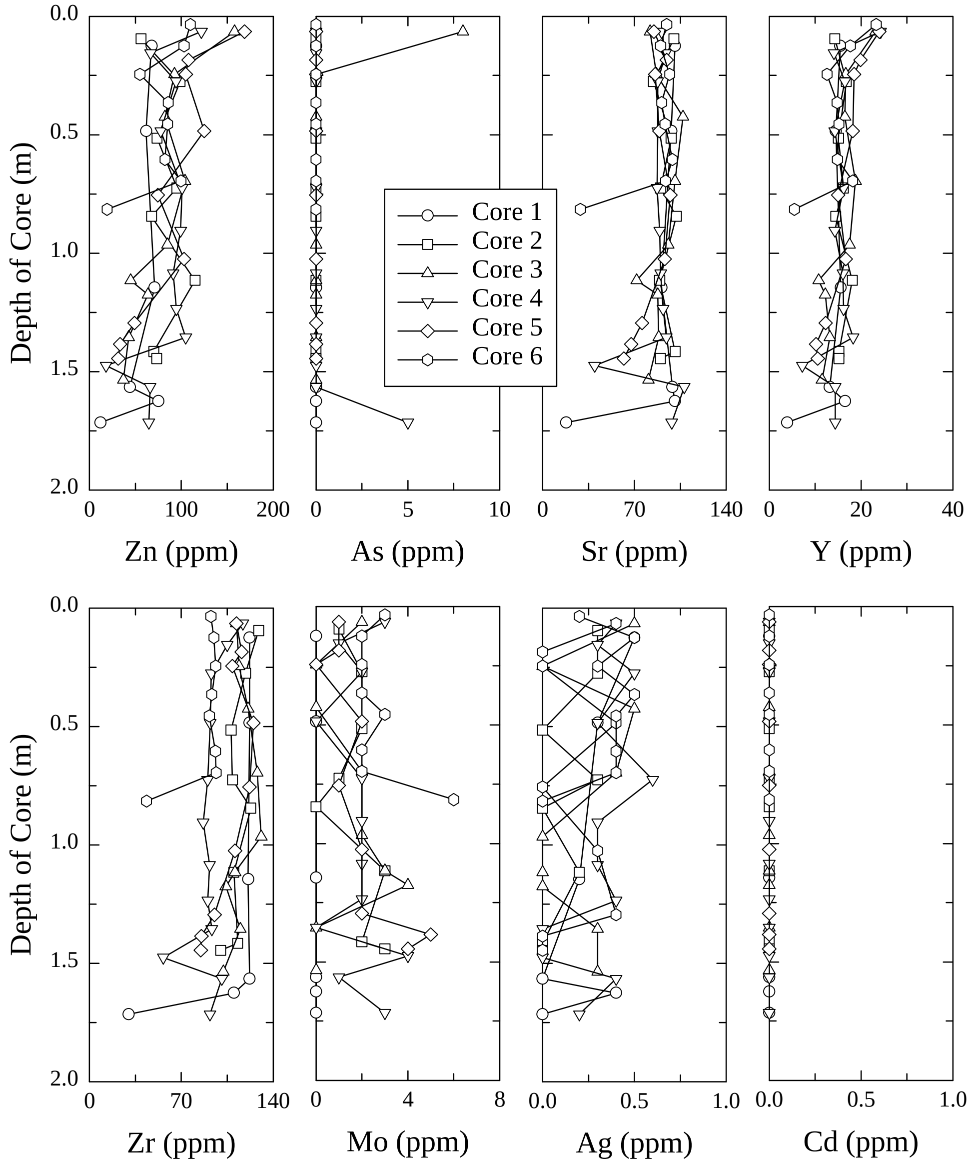

Figure 21. Summary of select chemical results (Zn, As, Sr, Y, Zr, Mo, Ag, and Cd) as a function of depth below the sediment surface (see Table 1 for detection limits, and Tables 2 through 7).

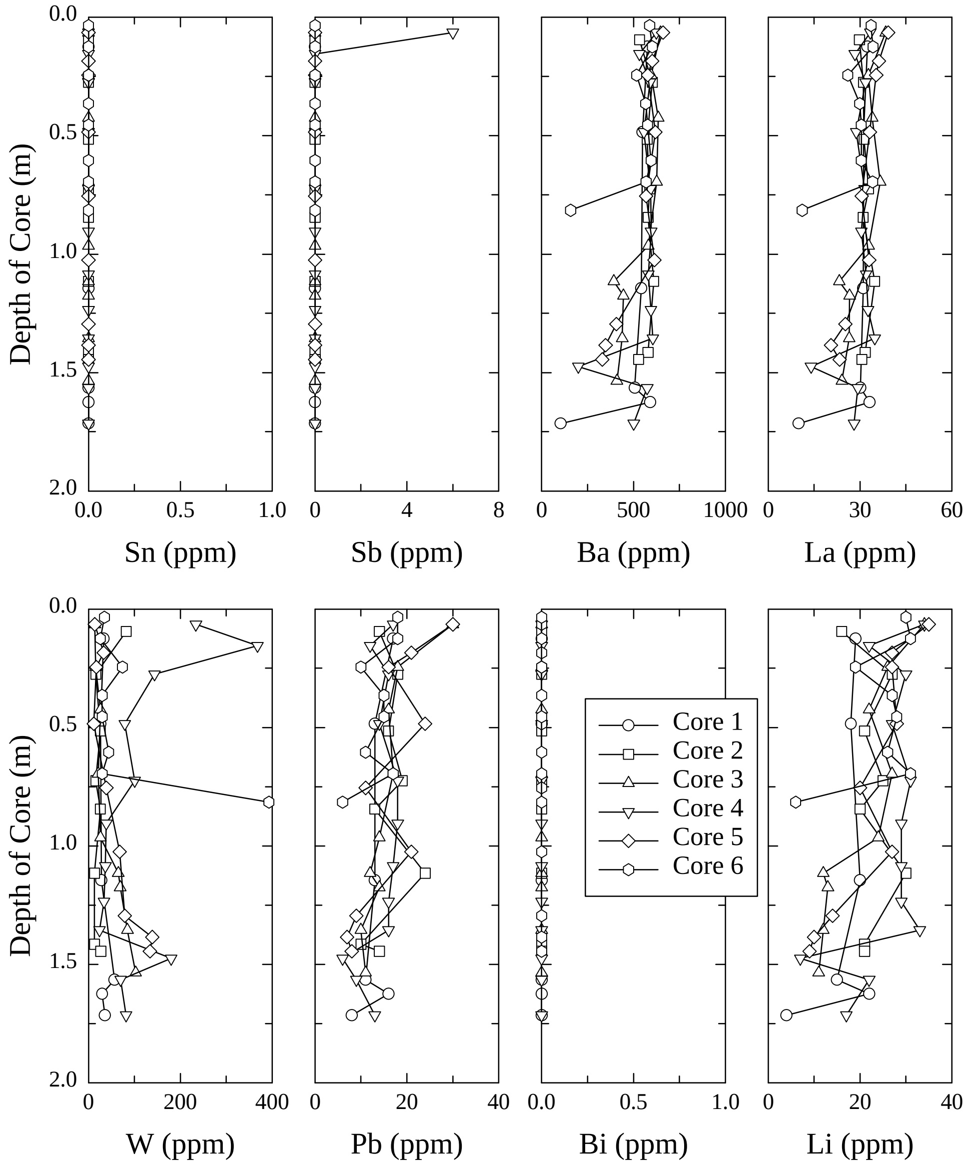

Figure 22. Summary of select chemical results (Sn, Sb, Ba, La, W, Pb, Bi, and Li) as a function of depth below the sediment surface (see Table 1 for detection limits, and Tables 2 through 7).

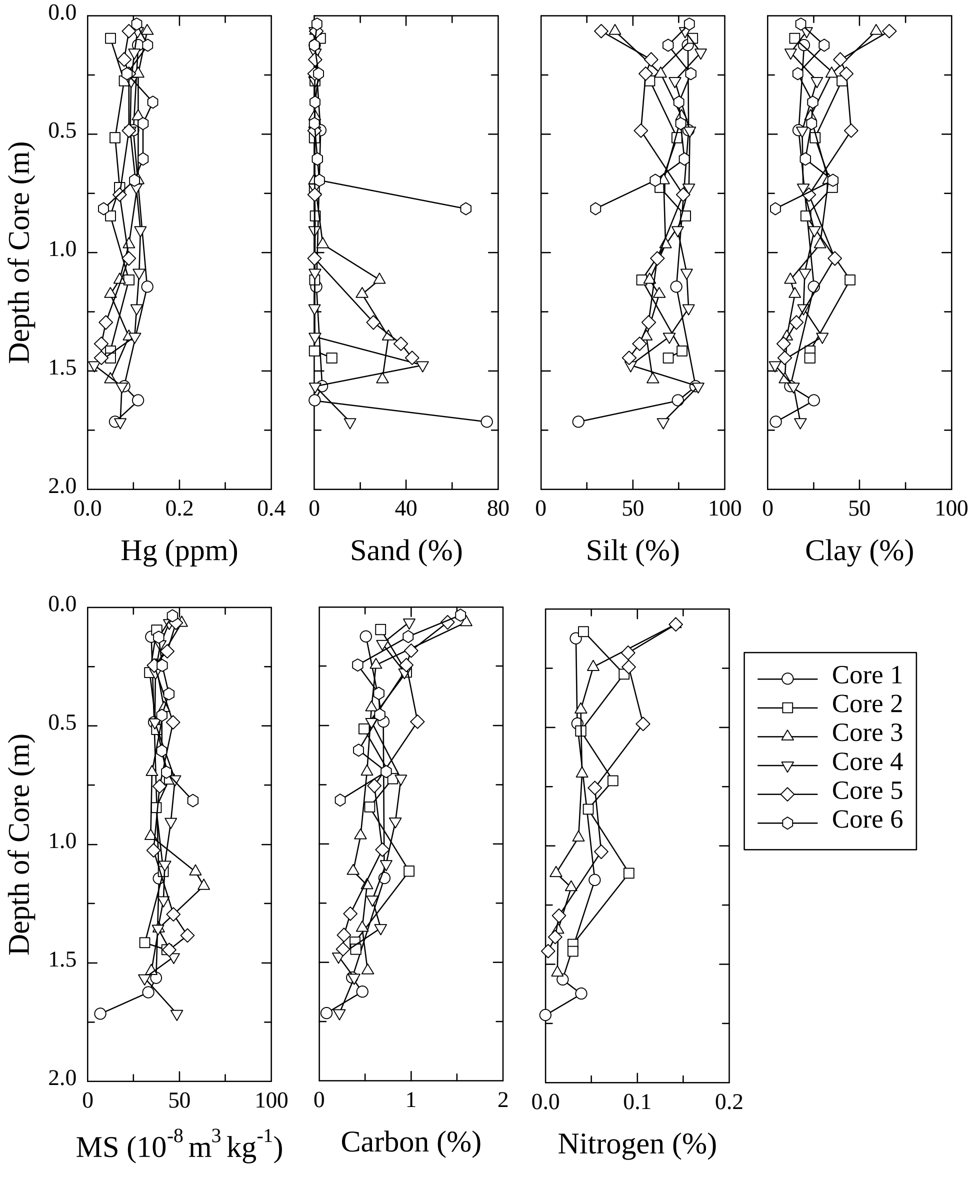

Figure 23. Summary of select chemical (Hg, C, and N) and physical (sand, silt, clay, and magnetic susceptibility) results as a function of depth below the sediment surface (see Table 1 for detection limits, and Tables 2 through 7).

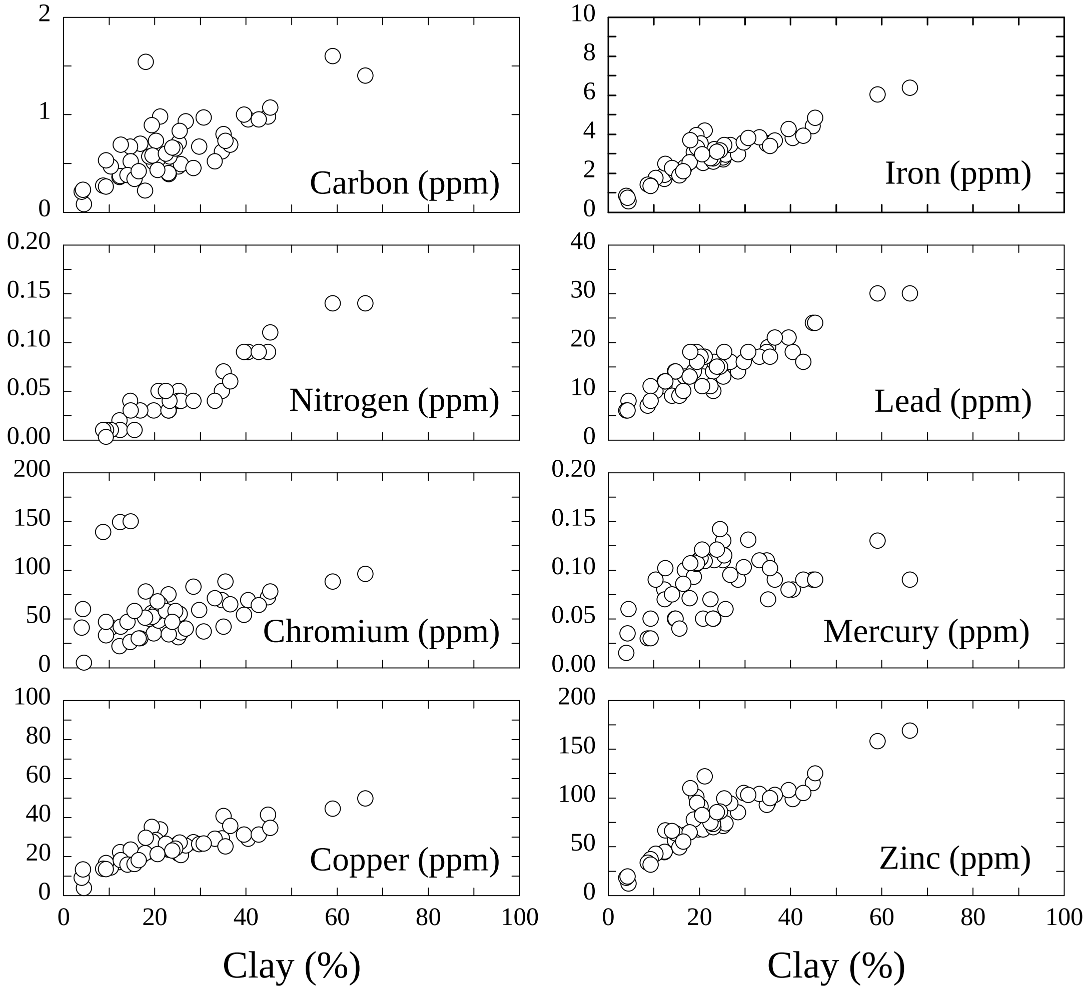

Figure 24. Concentration of select elements as a function of clay content for all sediment samples.

Discussion

The grain size results show that the sediment deposited within the reservoir is composed of 80% silt and 20% clay by weight. Only minor amounts of sand and gravel are found in the cores, and these grain sizes are restricted to the lowest sediment horizons. The magnetic susceptibility of sediment ranges from 30 to 63 10^{-8} m^3/kg, but most values typically fall in the 35 to 40 10^{-8} m^3/kg range and display little variation both within cores and from core to core. Very little nitrogen is present in the sediments at Hubbard-Murphree, typically much less than 0.1% by weight, and the average amount of carbon present is around 0.64%.

The concentrations of the 33 elements within the sediments do not vary significantly within each core or from core to core, although some elements decrease in concentration as depth increases. Element concentration is strongly correlated to the amount of clay within the sample.

With respect to establishing TMDL criteria for nutrients and elements associated with sediments, a table provided herein summarizes average concentrations for 33 elements spanning a time period of nearly 40 years. These average values can be used to establish natural or reference concentrations of elements, chemicals, compounds, and nutrients delivered to the waterbody via the sediment over several decades as well as to assess historical changes in land-use, hydrology, and agriculture as these pertain to watershed processes.

Several interpretations can be drawn from these data. Since the bulk composition, texture, and chemistry of the sediment do not vary significantly with time, the sources of the sediment or where erosion is taking place probably have not changed with time. Moreover, it is likely that the changes in hydrology, land-use, and agriculture during the period of record have had minimal effect on soil loss and channel erosion.

The ubiquitous gravel-laden sediment horizon near the base of each core probably defines the as-built sediment surface. Hence all sediment lying stratigraphically above these gravel-laden layers is post-construction deposition. Since the dam was built in the early 1960's and the sediment thickness above these gravel layers range from 0.75 to 1.65 m (typically 1.35 m), rates of sedimentation within the reservoir range from 20 to 42 mm/yr (typically 35 mm/yr) or 0.02 to 0.05 mm/ha-yr (typically 0.04 mm/ha-yr).

AGRICHEMICAL ANALYSIS OF RESERVOIR SEDIMENT

Sediment Sampling Methods and Procedures

As discussed previously, select cores were sampled for later agrichemical and chemical analysis. Approximately 1 to 2 kg of sediment was obtained from Core 4 and Core 6, integrated over the entire core length. These two samples were taken to Argus Analytical, Inc., Ridgeland, MS and were analyzed for 13 select metals, 3 herbicides, 26 organophosphorus pesticides, and 17 organochlorine pesticides and 7 PCBs (Priority Pollutant Pesticides/PCBs; Table 9). Agrichemical and heavy metal concentrations were determined using standard laboratory equipment such as gas chromatography, inductively coupled plasma-mass spectrometry, and atomic absorption according to the U.S. Environmental Protection Agency approved techniques (US-EPA, 1997).

Agrichemical Results and Discussion

The results of agrichemical and PCB analysis presented in Table 9 show that no compounds were found above their detectable limits. Moreover, the concentration of the metals from Core 4 and 6 determined by Argus Analytical, Inc. are compared to the average values determined by XRAL Laboratories as listed in Table 8. In general, the results from the two laboratories are quite comparable. However, the largest differences occur in Cr, Cu, Ni, and Zn. The small average value of As reported in the XRAL Laboratories for Core 4 is the result of only one positive detection, which was 5 ppm (Table 5).

Table 9. Sediment quality analysis of samples taken at Hubbard-Muphree Dam from sediment Cores 4 and 6 (Argus Analytical, Inc). Also included are the average values for select metals reported in Table 8 (XRAL Laboratories).

			Results			
			Core 4		Core 6	
Parameter	Units	DL	Argus	XRAL	Argus	XRAL
Metals Herbicides Organophosphorus Pesticides Priority Pollutant Pesticides/PCBs						
Antimony, Sb	ppm	1.25	ND	0.50	ND	ND
Arsenic, As	ppm	1.25	6.55	0.42	3.84	ND
Beryllium, Be	ppm	0.25	0.31	1.19	ND	1.20
Cadmium, Cd	ppm	0.5	ND	ND	ND	ND
Chromium, Cr	ppm	1.25	12.9	51.17	9.31	58.25
Copper, Cu	ppm	0.25	11.6	24.19	8.65	22.58
Lead, Pb	ppm	1.25	11.9	14.33	8.98	13.75
Mercury, Hg	ppm	0.1	0.214	0.09	ND	0.11
Nickel, Ni	ppm	0.5	15.5	34.00	11.3	39.75
Selenium, Se	ppm	1.25	ND	NA	ND	NA
Silver, Ag	ppm	0.125	ND	0.37	ND	0.34
Thallium, Tl	ppm	0.5	ND	NA	ND	NA
Zinc, Zn	ppm	1.25	66.3	83.39	57.2	80.01
Herbicides						
2,4-D	ppm	0.8	ND	NA	ND	NA
2,4,5-T	ppm	0.4	ND	NA	ND	NA
2,4,5-TP (Silvex)	ppm	0.4	ND	NA	ND	NA
Organophosphorus Pesticides						
Azinphos Methyl (Guthion)	ppm	0.333	ND	NA	ND	NA
Bolstar	ppm	0.333	ND	NA	ND	NA
Chlorpyrifos	ppm	0.333	ND	NA	ND	NA
Coumaphos	ppm	0.333	ND	NA	ND	NA
Demeton-S	ppm	0.333	ND	NA	ND	NA
Diazinon	ppm	0.333	ND	NA	ND	NA
Dichlorvos	ppm	0.333	ND	NA	ND	NA
Dimethoate	ppm	0.333	ND	NA	ND	NA
Disulfoton	ppm	0.333	ND	NA	ND	NA
EPN	ppm	0.333	ND	NA	ND	NA
Ethoprop	ppm	0.333	ND	NA	ND	NA
Ethyl parathion	ppm	0.333	ND	NA	ND	NA
Fensulfothion	ppm	0.333	ND	NA	ND	NA
Fenthion	ppm	0.333	ND	NA	ND	NA

Table 9 continued

			Results			
			Core 4		Core 6	
Parameter	Units	DL	Argus	XRAL	Argus	XRAL
Malathion	ppm	0.017	ND	NA	ND	NA
Merphos	ppm	0.333	ND	NA	ND	NA
Methyl parathion	ppm	0.033	ND	NA	ND	NA
Mevinphos	ppm	0.333	ND	NA	ND	NA
Monocrotophos	ppm	0.333	ND	NA	ND	NA
Naled	ppm	1.670	ND	NA	ND	NA
Phorate	ppm	0.333	ND	NA	ND	NA
Ronnel	ppm	0.333	ND	NA	ND	NA
Stirophos	ppm	0.333	ND	NA	ND	NA
TEPP	ppm	0.333	ND	NA	ND	NA
Tokuthion	ppm	0.333	ND	NA	ND	NA
Trichloronate	ppm	0.333	ND	NA	ND	NA
Priority Pollutant Pesticides/PCBs						
Aldrin	ppm	0.0017	ND	NA	ND	NA
Alpha-BHC	ppm	0.0017	ND	NA	ND	NA
Beta-BHC	ppm	0.0017	ND	NA	ND	NA
Gamma-BHC (Lindane)	ppm	0.0017	ND	NA	ND	NA
Delta-BHC	ppm	0.0017	ND	NA	ND	NA
Chlordane	ppm	0.0017	ND	NA	ND	NA
4,4’-DDT	ppm	0.0033	ND	NA	ND	NA
4,4’-DDE	ppm	0.0033	ND	NA	ND	NA
4,4’-DDD	ppm	0.0033	ND	NA	ND	NA
Dieldrin	ppm	0.0033	ND	NA	ND	NA
Endosulfan I	ppm	0.0017	ND	NA	ND	NA
Endosulfan II	ppm	0.0033	ND	NA	ND	NA
Endosulfan sulfate	ppm	0.0033	ND	NA	ND	NA
Endrin	ppm	0.0033	ND	NA	ND	NA
Endrin aldehyde	ppm	0.0033	ND	NA	ND	NA
Heptachlor	ppm	0.0017	ND	NA	ND	NA
Heptachlor epoxide	ppm	0.0017	ND	NA	ND	NA
PCB-1016	ppm	0.0333	ND	NA	ND	NA
PCB-1221	ppm	0.0667	ND	NA	ND	NA
PCB-1232	ppm	0.0333	ND	NA	ND	NA
PCB-1242	ppm	0.0333	ND	NA	ND	NA
PCB-1248	ppm	0.0333	ND	NA	ND	NA
PCB-1254	ppm	0.0333	ND	NA	ND	NA
PCB-1260	ppm	0.0333	ND	NA	ND	NA
Toxaphene	ppm	0.0333	ND	NA	ND	NA

ppm—parts per million; DL—detection limit; ND—not detected; NA—not available

CONCLUSIONS

Since 1944, the USDA-NRCS has constructed nearly 11,000 upstream flood control dams in 2000 watersheds in 47 states, each with a design life of 50 years. The watershed projects, which represent a $14 billion infrastructure, have provided flood control, municipal water supply, recreation, and wildlife habitat enhancement. Because of population growth and land use changes through time, sediment pools are filling, some structural components have deteriorated, safety regulations are stricter, and the hazard classification for some dams has changed.

Before any rehabilitation strategy can be designed and implemented, the sediment impounded by these dams must be assessed in terms of the structure's efficiency to regulate floodwaters and the potential hazard the sediment may pose if reintroduced into the environment. For a given lake within an embankment flood control structure, the USDA-NRCS needs to determine (1) the volume of sediment deposited, (2) the rates of sedimentation, (3) the quality of sediment with respect to agrichemicals (related to agricultural practices) and other contaminants, and (4) the spatial distribution of the sediment quality. To this end, a project was designed to collect continuous, undisturbed sediment cores from the sediment pool of Hubbard-Murphree Dam Y-17-73 and to evaluate the physical and chemical characteristics of the sediment.

Reservoirs such as Hubbard-Murphree represent a nearly 40-year record of continuous sedimentation. This record of deposition provides a number of opportunities to assess Total Maximum Daily Load (TMDL) criteria for sediment, chemicals, and nutrients. These include: (1) the quality of the sediment can be used to determine natural or reference concentrations of elements, chemicals, compounds, and nutrients delivered to the waterbody via the sediment over several decades, (2) the quality of the sediment can be used to assess historical changes in land-use, hydrology, and agriculture as these pertain to watershed processes, and (3) the uncovered or dredged sediment may have significant adverse effects on the aquatic environment and water quality both within and downstream of the reservoir.

Hubbard-Murphree Dam Y-17-73 is located near Charleston, MS and it is a relatively small lake with a mud bottom and fairly shallow water depths (up to 2 m). Dam construction was completed in the early 1960's. The reservoir has an upstream drainage area of 2,030 acres (822 ha).

A commercially available vibracoring system was used to obtain 6 undisturbed cores of unconsolidated sediment in nearly saturated conditions at Hubbard-Murphree. These cores ranged in length from 0.9 to 1.8 m and were extracted from water depths ranging from 0.6 to 1.5 m. The physical, chemical, agrichemical, and contaminant characteristics of the sediment within these cores were determined. Below are the major conclusions of the study.

1. In general, the sediment cores extracted at the Hubbard-Murphree reservoir are composed of clay, silt, sand, and gravel of varying proportions. Most cores have alternating layers of silty clay, silty clay loam, and silt loam. Most noteworthy is the ubiquitous gravel-laden sediment horizon near the base of each core.

2. The grain size results show that most of the sediment deposited within the reservoir is composed of 80% silt and 20% clay by weight. Only minor amounts of sand and gravel are found in the cores, and these grain sizes are restricted to the lowest sediment horizons. The magnetic susceptibility of sediment display little variation. Very little nitrogen is present in the sediments at Hubbard-Murphree, typically much less than 0.1% by weight, and the average amount of carbon present is around 0.64%.

3. The concentrations of the 33 elements within the sediments do not vary significantly within each core or from core to core, although some elements decrease in concentration as depth increases. Element concentration is strongly correlated to the amount of clay within the sediment sample.

4. With respect to establishing TMDL for nutrients and elements associated with sediments, a table provided herein summarizes average concentrations for 33 elements spanning a time period of nearly 40 years. These average values can be used to establish natural or reference concentrations of elements, chemicals, compounds, and nutrients delivered to the waterbody over several decades as well as to assess historical changes in land-use, hydrology, and agriculture as these pertain to watershed processes.

5. Since the bulk composition, texture, and chemistry of the sediment do not vary significantly with time, the sources of the sediment or where erosion is taking place probably have not changed with time. Moreover, it is likely that the changes in hydrology, land-use, and agriculture during the period of record have had minimal effect on soil loss and channel erosion.

6. The ubiquitous gravel-laden sediment horizon near the base of each core probably defines the as-built sediment surface. Hence all sediment lying stratigraphically above these gravel-laden layers is post-construction deposition. Since the dam was built in the early 1960's, and the sediment thickness above these gravel layers range from 0.75 to 1.65 m (typically 1.35 m), rates of sedimentation within the reservoir range from 20 to 42 mm/yr (typically 35 mm/yr) or 0.02 to 0.05 mm/ha-yr (typically 0.04 mm/ha-yr).

7. Two depth-integrated sediment samples were analyzed for 3 herbicides, 26 organophosphorus pesticides, 17 organochlorine pesticides, and 7 PCBs. Results of this analysis show that no compounds were found above their detectable limits.

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